(2)

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

THE EFFECTS OF A PITCHED FIELD ORIENTATION ON HAND/EYE COORDINATION

by

Cynthia J. Ballinger

September 1988

Thesis Advisor: Thomas M. Mitchell

Approved for public release; distribution is unlimited.

Unclassified

Security Classification of this page

REPORT DOCUMENTATION PAGE

1a Report Security Classification Unclassified	1b Restrictive Markings
2a Security Classification Authority	3 Distribution Availability of Report Approved for public release; distribution is unlimited.
2b Declassification/Downgrading Schedule	
4 Performing Organization Report Number(s)	5 Monitoring Organization Report Number(s)
6a Name of Performing Organization Naval Postgraduate School — 6b Office Symbol (If Applicable) 39	7a Name of Monitoring Organization Naval Postgraduate School
6c Address (city, state, and ZIP code) Monterey, CA 93943-5000	7b Address (city, state, and ZIP code) Monterey, CA 93943-5000
8a Name of Funding/Sponsoring Organization — 8b Office Symbol (If Applicable)	9 Procurement Instrument Identification Number
8c Address (city, state, and ZIP code)	10 Source of Funding Numbers Program Element Number / Project No / Task No / Work Unit Accession No

11 Title (*Include Security Classification*) The Effects of a Pitched Field Orientation on Hand/Eye Coordination.

12 Personal Author(s) Cynthia J. Ballinger

13a Type of Report	13b Time Covered	14 Date of Report (year, month,day)	15 Page Count
Master's Thesis	From To	September 1988	70

16 Supplementary Notation The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

17 Cosati Codes			18 Subject Terms (*continue on reverse if necessary and identify by block number*)
Field	Group	Subgroup	Pitched Visual Field Orientation, Hand/Eye Coordination.

19 Abstract (*continue on reverse if necessary and identify by block number*

Ten subjects judged eye level by making verbal and pointing responses while looking into a box that was pitched at angles of approximately -15, -7.5, 0, 7.5 and 15 degrees. The mean verbal judgements changed as a function of the box's pitch angle according to the relationship:

Judged Eye Level = 0.48 (Box Pitch Angle) - 0.31 Degrees

which agrees with the results of previous studies. The mean pointing responses were also a function of the box's pitch angle:

Pointing Response = -0.19(Box Pitch Angle) - 5.39 Degrees

Thus, the mean pointing responses change at approximately 40 percent of the rate of the perceptual responses, as indicated by the verbal judgements, and are in the opposite direction. These errors have implications for the design of displays and controls for vehicles that operate in environments where pitched visual fields are encountered. [illegible]: visual perception; military theses; hand-eye coordination; (KT)

20 Distribution/Availability of Abstract [X] unclassified/unlimited [ ] same as report [ ] DTIC users	21 Abstract Security Classification Unclassified
22a Name of Responsible Individual T. Mitchell	22b Telephone (Include Area code) (408) 646-2381 — 22c Office Symbol T. 55MI

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted — security classification of this page

All other editions are obsolete — Unclassified

Approved for public release; distribution is unlimited.

The Effects of a Pitched Field Orientation
on Hand/Eye Coordination

by

Cynthia J. Ballinger
Lieutenant, United States Navy
B.S., University of Florida, 1981

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS TECHNOLOGY
(SPACE SYSTEMS OPERATIONS)

from the

NAVAL POSTGRADUATE SCHOOL
September 1988

Author: Cynthia J. Ballinger
Cynthia J. Ballinger

Approved By: Thomas M. Mitchell
Thomas M. Mitchell, Thesis Advisor

Malcolm M. Cohen
Malcolm M. Cohen, Co-Advisor

Otto Heinz for R. Panholzer
Rudolph Panholzer, Chairman, Space Systems Academic Group

G E Schacher
George E. Schacher, Dean of Science and Engineering

ABSTRACT

Ten subjects judged eye level by making verbal and pointing responses while looking into a box that was pitched at angles of approximately -15, -7.5, 0, 7.5 and 15 degrees. The mean verbal judgements changed as a function of the box's pitch angle according to the relationship:

Judged Eye Lvel = 0.48 (Box Pitch Angle) - 0.31 Degrees

which agrees with the results of previous studies. The mean pointing responses were also a function of the box's pitch angle:

Pointing Response = -0.19(Box Pitch Angle) - 5.39 Degrees

Thus, the mean pointing responses change at approximately 40 percent of the rate of the perceptual responses, as indicated by the verbal judgements, and are in the opposite direction. These errors have implications for the design of displays and controls for vehicles that operate in environments where pitched visual fields are encountered.

TABLE OF CONTENTS

I. INTRODUCTION

A. OVERVIEW

Several studies have examined the effects of prisms on hand/eye coordination and the effects of a tilted environment on visual judgements of eye level. However, the effects of a pitched environment on hand/eye coordination have not been studied systematically. An experiment was performed to determine how a pitched visual field orientation affects a subject's perception of eye level and the subject's ability to point to a target at eye level without observing his/her hand. The experiment required subjects to look into a box that was pitched at one of five different angles. A series of numbers ran along the back of the box. The subject was asked to report what number appeared to be at eye level for one part of the experiment. During another part of the experiment, the subject was given a number by the experimenter and asked to reach and point to a spot on a touchboard to the right that corresponded to that number. For both parts of the experiment, the error between the subject's response, whether verbal or pointing, and the objective eye level was measured. The advantage of using this method instead of using prisms is that the optical path remains unchanged so that any change in the subject's perception of eye level is caused by the actual visual environmental, not by optical or physiological factors.

B. LITERATURE REVIEW

1. Proprioceptive System

Sherrington in 1906 proposed the terms "exteroceptive field" and "proprioceptive field" to categorize sensory systems. The exteroceptive field refers to the sensory systems that respond to stimulation that originates outside of the organism. This requires a large number of diverse receptors due to the large variety of stimulation arising from events occurring in the outside world. The proprioceptive field describes the sensory systems that are stimulated by events occurring within the organism. These receptors are particularly well adapted to respond to mechanical forces within the organism. Some action or change in spatial position of the organism is the primary cause of the excitation of the proprioceptive receptors. [Ref. 1:pp. 175-176]

According to Sherrington, the functioning of the central nervous system is essentially circular. The initiation of motor activity is primarily in response to exteroceptive stimulation. The proprioceptors then provide the central nervous system with information about changes in position caused by motor activity. The central nervous system requires this input to coordinate and modify future motor activity. Thus, proprioceptive feedback asserts a continuous influence on spatial orientation, posture and locomotion. [Ref. 1:p. 176]

Three general groupings of proprioceptive receptors fall within Sherrington's framework. These are the muscle proprioceptors, the joint and cutaneous proprioceptors, and the labyrinthine proprioceptors, all of which contribute to the perception of spatial orientation, visual direction, and spatially directed motor activity. [Ref. 1:pp. 176-177]

Neuromuscular spindles and Golgi tendon organs are muscle proprioceptive receptors that reside within the gross structure of most striated muscles. Distributed among a muscle's extrafusal (contractual) fibers are the neuromuscular spindles that act basically as stretch receptors and respond to changes of the length of the fiber. They receive both afferent and efferent innervation which ensures that the neuromuscular spindles keep a high degree of sensitivity and precision no matter what the muscle length and load is. [Ref. 1:p. 178]

The Golgi tendon organs are small capsules that lie in the connective tissues at the muscle-tendon junction. Golgi tendon organs are activated when the individual motor units of their respective muscles are electrically stimulated to contract. Localized tensions within their respective muscle group, rather than gross tension of the entire muscle group, appear to be what the Golgi tendon organs respond to. [Ref. 1:pp. 178-179]

Although the extraocular muscle of the human eye does have proprioceptive receptors that transmit afferent neural impulses to the brain, it appears that these proprioceptors do not contribute to the conscience awareness of eye position. The muscle spindles probably do send information that is used to adjust and compensate for changes of eye position. [Ref. 1:pp. 178-179]

The joints, the skin and the connective tissue have proprioceptive receptors that vary greatly in shape size and anatomical complexity, many of which play a dual role as proprioceptors and exteroceptors. These receptors are sensitive to pressure, and provide the central nervous system with information concerning alterations in the distribution of pressure caused by changes in body position and orientation. [Ref. 1:pp. 180-181]

The semicircular canals and the otolith organs are highly specialized organs that comprise the labyrinthine (or vestibular) system, which is located in the nonauditory part of each inner ear. The vestibular system aids in the maintenance of posture and equilibrium. It also has a crucial role in the perception of motion and spatial orientation and causes reflex responses in the extrinsic ocular muscles, helping to stabilize the position of the eyes relative to external space whenever the head is moved. [Ref. 1:pp. 182-185]

2. The Effect Of Prisms On Hand/eye Coordination

A typical way to study the effect of a prism on vision is to place a base left or base right 20-diopter wedge prism before one or both eyes. The prisms are usually mounted in a pair of goggles. The result of this is an approximately 11 degree lateral rotation of the visual field in the direction of the prism's apex. When exposure to a prism involves pointing to an object, the initial reaching attempts are in error by a significant amount. However, the visual feedback that results concerning errors usually leads to a complete correction of the pointing behavior after only a few trials. After the prism is removed, the subject continues to reach to the spot that feels as if it is in line with the target, disregarding where the target actually appears. This is called the visuomotor negative after-effect. [Ref. 2:pp. 13-21]

There are a number of possible reasons for the negative aftereffect that follows prism exposure. One of these is a changes in the felt position of the arm. During the pre-exposure period, visual feedback is precluded. The arm is felt to be where it actually is, and the subject is relatively accurate in reaching for a target even though the arm is not seen at this time. At the beginning of the prism exposure period, the subject sees the target at a position that is shifted to the right of its actual location. The subject reaches for the apparent position of the target and errs to the right. The arm is felt to be where it actually is. The arm, like the target, will appear to the right of its actual position due to the prism. By the end of the prism exposure period, the subject is reaching accurately for the target, although he is still seeing both target and arm to the right of their true positions. However, the felt position of the arm now coincides with its observed position. This resolution of the intersensory discordance accounts for the accuracy of reaching. When the prism is removed, and visual feedback is once more precluded, the subject will err to the left of the target, since only when he positions his arm in this way does it feel as if the arm is in line with the target. [Ref. 2:pp. 49-50]

The following are other possible causes of the negative aftereffect:

1. Conscience correction of one's aim: The subject, while looking through prisms, misses the target and realizes that the prisms are causing him to mistake where the target actually is . The subject deliberately aims to one side of the visual target and should go back to pointing at the target when the prisms are removed.
2. Altered visual perception: A changed translation from the retinal image to perception makes a target that initially appeared to be off to the side now seem to be straight ahead. Any appropriate judgement or response to a target seen either with or without prisms should demonstrate this new perception.
3. Reorientation of the perceptual frame of reference: Perception of all external stimuli, visual or auditory, except perception of the arms, is shifted to one side.
4. Visuomotor recorrelation: Visual perception does not change. Instead, a given visual input is paired with a different motor output. The unexposed arm is not affected since only the visuomotor system is used during adaptation.
5. Motor-response learning: A new motor response is acquired by the practiced arm in response to a stimulus from a give spatial location regardless of the modality of that stimulus. A generalization occurs when the subject uses arm movements that were different from the practiced one.

[Ref. 3:pp. 20-23]

An experiment was done by Harris to try to determine the reason for the adaptation. Prior to being exposed to the prisms, the subject practiced pointing to visual targets, to auditory targets and straight ahead. The subject was not allowed to view his hand during this period. The subject then looked through a prism and pointed with one hand (all four possible combinations of right/left hand and right/left prisms were tested) to a visual target. Initially all subjects missed pointing to the target but soon adapted. The following were the results of the experiment:

1. The aftereffect transferred to all targets, regardless of the target's modality.
2. There was little or no transfer of the effects to the unadapted hand (intermanual transfer).

[Ref. 4:p. 812]

These results rule out the possibility that the aftereffects were due to a conscience change of aim by the subject, since the subject continued to show the effects after the prisms were removed and could not accurately point to a target. If the aftereffect was caused by a change of visual perception, then there should have been an intermanual transfer of the effects since the object would appear off to the side no matter what hand was used to point. There was no intermanual transfer of the effects, so a change in perception can be ruled out. If the aftereffect was caused by a change in the correlation between vision and behavior it should only apply to visual targets. However, the effect transferred to targets with modalities different from vision. If the aftereffect was caused by learning specific new motor responses, it should not have been generalized to arm movements different from the ones used during the period when the subject viewed the target through the prisms. However, the subject was able to point to the other types of targets even though this required different arm motions. Thus, a change of proprioceptive perception seems to determine the aftereffect. If the visual and proprioceptive receptors provide conflicting information to the subject (if the hand looks like it is at one place but feel that it is at another) the visual cues will dominate the proprioceptive ones, and the subject will begin to feel that his hand is where it looks like it is. [Ref. 4:p. 813]

A series of experiments were done by Efstathiou, Bauer, Greene, and Held that questioned this idea. They claimed that:

> Adaptation of eye-hand coordination to displacement then results from the establishment of a new set of matched orientations between the exposed arm and the head. The result is a shift in the reaching for visual targets with that hand.

[Ref. 5:p. 116]

For example, after looking through a prism, the subject cannot accurately reach for his other hand, even though he can do this with his eyes closed. When the subject's eyes are closed, he receives information from the proprioceptive receptors concerning the position of his hand, arm and shoulder and uses this information to reach for the other hand accurately. If only one hand has been adapted after prism exposure, its matched orientation to the head has been changed, though the matched orientation of the other hand has remained the same. Thus, there is a discrepancy between the matched orientation of the two hands, which causes the reaching error. However, the magnitude of the unexposed arm's aftereffect tended to decrease as the rate of responding (during the prism exposure session) increased. [Ref. 5:p. 116]

3. The Effects of the Tilted Visual Field

There are three aspects of spatial vision that should be defined prior to a discussion on the effect of tilting the visual field. The first of these is environmental orientations. When a typical scene is viewed using normal vision, the objects appear to be oriented in some fashion with respect to their environment. They seem to be in line with or at variance from the vertical or horizontal dimensions of the world. The visual framework and the perceived direction of gravity are two major sources of environmental orientation. The second aspect of spatial vision is egocentric orientation, which is the perceived relation of the visual environment to the observer. The third aspect is egocentric direction; an object is perceived as having a particular radial direction relative to the observer. [Ref. 2:pp. 115-118]

When a subject is upright, environmental and egocentric orientation coincide. This redundancy of physical orientation when in an upright position may account for the accuracy in discerning the orientation of objects. Environmental and egocentric orientations are no longer the same when the subject's head or entire body is tilted relative to gravity, because gravitationally vertical objects become tilted egocentrically in the opposite direction. [Ref. 2:p. 137]

A method has been developed to specify the principle planes and axes of the human body. The vertical axis which passes through the center of gravity of the body when the person is upright is referred to as the mid-body or z-axis. It is also called the yaw axis. The plane of bilateral body symmetry containing the mid-body axis is referred to as the median (mid-sagital) plane or y-axis, and is also called the pitch axis. The plane perpendicular to the mid-body and median plane is referred to as the mid-transverse plane or x-axis and is also known as roll axis. [Ref. 6:pp 6-7]

a. The Effects of a Visual Field Tilted in the Roll Dimension

The studies investigating the effect of tilt in the roll direction usually consist of a darkened room with a luminous line that is viewed by the subject whose head or entire body is tilted to the left or right. In general, the subject's perception of gravitational vertical remains relatively constant, even with large body tilts. Gravitational and postural cues allow the retinal image to be "discounted". This does not mean that the constancy of gravitational vertical is perfect. [Ref. 2:p. 137] For example, for tilts up to about 45 degrees, a line must be rotated beyond the true vertical and in the direction opposite that of the subject's own body tilt in order for that line to appear upright (in line with the direction of gravity). This is known as the E effect. With large body tilts, between 45 and 90 degrees, the line must be rotated in the same direction as the observer in order for it to be perceived as vertical. This is called the A effect. [Ref. 7:p. 1] Both the A and E effects are departures from perfect vertical orientation, indicating that the perception of visual-gravitational vertical is less accurate when gravitational cues are present without a visual framework. [Ref. 2:pp. 137-138]

The roles and relative importance of visual and postural cues in determining vertical or horizontal were studied by Asch and Witken using subjects who were positioned standing erect looking into a mirror that presented an environment that appeared tilted 30 degrees. This separates the visual from postural components since the subject's body remains upright while the visual components are displaced. The subject looked at the mirror through a tube for the first part of the experiment and without the tube for the second. The subject was instructed to look at a rod that the experimenter was moving and to tell the experimenter to stop moving the rod when it was parallel to his body position. Thus, the subject was to use postural, not a visual standard to specify when the rod was vertical. The results of the experiment were a 21.5 degree deviation from true vertical when the subject viewed the mirror through the tube and a 26.4 degree deviation from true vertical when no tube was used. These results suggest that visual factors are more important than postural cues in the perception of vertical. There were considerable individual differences in the judgements, though most subjects were influenced by the tilted field by a significant amount. Some subjects even perceived the tilted field to be upright. [Ref. 8:pp. 329-337]

A second experiment was performed using an actual room tilted 22 degrees from the vertical. In the first part, the subject stood erect throughout the trials. The second part of the experiment was similar except, the subject was placed directly in front of the tilted room with his legs actually touching the sloping floor of the room. During the third part of the experiment the subject was placed at a distance of about six feet from the tilted room. The subject could see the surrounding upright room under this condition. The results for all three conditions were that most subjects perceived vertical as closer to the tilt of the room than to true vertical . [Ref. 9:p. 457]

In the third experiment, subjects were seated in a chair that was tilted 24 degrees to the left. The chair was postioned in front of a room that was tilted 22 degrees to the right. This created a disparity of 46 degrees between the vertical of the subject's body and the vertical of the room. The subject saw the chair and the room when he first enter the labratory, so that he knew that both the chair and the room were tilted. For the first test, the subject had a full field of view of the tilted room and the surrounding room. Immediately after this test, a tube was placed in front of the subject's face and another series of determinations were taken. [Ref. 9:pp. 467-468]

Even though they knew that the room and chair were tilted, the subjects' vertical and horizontal judgements deviated from true horizontal and vertical in the direction of the tilted visual field. When the subjects' field of view of the room was restricted by the tube, there was, as a group, an increase in the deviations of the judgement. There were individual differences in both cases. When the tube was removed, all the subjects reported that there was an increase in the perceived tilt of the room. [Ref. 9:pp. 469-472]

The results of these experiments suggest that tilting the body increases the difficulty of using postural cues as a basis for judging upright. The reliance upon the visual framework for cues increases, as postural factors became less useful. This is particularly striking since gravitational vertical does not change when the body is tilted, though the ease with which its direction is determined is affected. Thus, minor changes in the postural cues impair their usefulness in determining true vertical, suggesting that they have a relatively limited role and have a maximum impact when the body is erect and when no contradictory visual field is present. [Ref. 9:pp. 472-473]

If the visual field is upright, changes in body tilt do not cause errors in the perception of upright, though tilting the visual field when the body is erect causes error in the perception of upright. Maintenance of body position itself is influenced by the surrounding visual field. In the tilted room situation, some subjects experienced a loss of balance when there was a sudden shift from one visual frame of reference to another. [Ref. 9:pp. 473-474]

Two major properties of a visual field are important in spatial orientation:

1. Providing of a unitary visual framework: If the tilted visual field is the only field present, it has more of an effect than if the normal upright surrounding is also visible.
2. Providing articulation of the visual array: a more articulated field (more filled with contours) has a stronger effect than a relatively empty field.

[Ref. 9:pp. 473-474]

A third group of studies was done to determine how upright is established when there is no surrounding visual field. These studies were done in a darkened room with a luminous rod so that the subject could not see his surroundings. In the first experiment, only the subject's head was tilted. In the second experiment, the subject's whole body was tilted 42 degrees and then 28 degrees. In the third experiment, the subject's body was placed in a horizontal position. In the fourth experiment the subject stood erect. [Ref. 10:pp. 603-604]

When the body was erect, and in the absence of a surrounding visual field, subjects could determine vertical and horizontal very accurately. When the body was tilted, three changes took place:

1. Horizontal and vertical were not accurately determined, and the magnitudes of the errors varied with tilt. The largest errors occurred when the body was at the horizontal. There were also individual differences in the magnitude of the error.
2. There was no consistency in successive judgements made by the same individual. Over the series of trials, there was a range of positions that appeared upright to the subject. This variability was not found when a visible framework, even if tilted, was presented.
3. The subjects had more difficulty in making judgements. Subjects took longer to make a decision and were then unsure about its accuracy. This was not the case when the subjects stood erect or when a visual field was present.

[Ref. 10:pp. 610-611]

If the lights are turned on, restoring a visual field, the errors are eliminated, even when the subject is tilted. [Ref. 10:p. 612]

There was a consistency in the direction of errors as predicted by E and A effects. For small tilts, the rod tended to be disposed in a direction opposite that of the body (E-effect) and toward the body for large tilt (A-effect). These effects only occur when the visual field is absent . [Ref. 10:p. 612]

An experiment was performed by Bauremeister to study the effects of body tilt on a subject's perception of vertical and a subject's perception of the amount of tilt of his own body. The subject's entire body was tilted both right and left to angles ranging from 0-90 degrees (at 10 degree increments). The subject then told the experimenter how to position a luminous rod so that it was "straight up and down" (vertical) or "in line with the subject's body (coinciding in direction with the subject's longitudinal body axis)." [Ref. 11:pp. 142-143]

The following results were obtained:

1. For apparent vertical: an increase in body tilt resulted in the changing deviation of apparent from objective vertical. For tilts of 0-10 degrees, there tended to be a displacement of apparent vertical from objective vertical in the direction of the body tilt. This tendency was reversed for angles from 10 to 50 degrees right or 10 to 40 degrees left, so that the apparent vertical increasingly deviates from objective vertical in a direction opposite that of the body tilt. For angles 50 to 90 degrees right and 40 to 90 degrees left, the tendency reversed again so that the increasing displacement between objective and apparent vertical is in the direction of body tilt.
2. For apparent body position: An increase in body tilt resulted in a change in the perception of apparent body position. The deviation of judgements of apparent body position and objective body position followed a pattern similar to that of judgements of apparent vertical.
3. Relation between apparent vertical and body position: Both the deviation of apparent vertical from objective vertical and apparent body position from objective body position showed reversals in direction with respect to the direction of body tilt. The

deviation of apparent body position in the direction of tilt was greater than the deviation of apparent vertical for all positions of tilt. [Ref. 11:pp. 143-147]

In a study done by Bauermeister, Werner, and Wapner, blindfolded subjects had to adjust a metal bar to a position which appeared vertical (apparent vertical) while experiencing body tilts ranging from 90 degrees left to 90 degrees right. Adjustments were made using both hands, only the right hand, and only the left hand. The following results were obtained:

1. Increased body tilt led to changing deviation of apparent from objective vertical regardless of whether one or both hands were used. Up to approximately 70 degrees, there were increasing displacements of apparent from objective vertical opposite the direction of body tilt. If the tilt was increased up to 90 degrees, this tendency was reversed.
2. There were differences in the effect of body tilt on apparent vertical depending on the hands used. Adjustments with the left hand were located to the right of adjustments using both hands, and the adjustments using the right hand were located to the left of adjustments with both hands.

[Ref. 12:pp. 456-457]

b. The Effects of a Visual Field Tilted in the Pitch Dimension

A study was perfomed by Cohen and Larson to examine perceived body tilt in the pitch dimension by requiring the subject to adjust his body's pitch to each of 13 different goal orientations. The subject was placed in a supine position in a hospital bed that could be positioned from 90 degree forward (prone position) to 90 degress backward (supine position). The room was darkened. Initially, the bed was set at the erect position by the experimenter. For one sequence of trials, the subject was instructed to change the position of the bed so that he thought that his body was now postioned in a prone position, and then at increments of 15 degrees, to position his body back to supine. The order was reversed for the other sequence. The amount that the subject's body position differed from the goal position was measured in degrees. The results indicated that when the subjects were tilted less than 60 degrees backward or forward, they underestimated body tilt. When subjects were in a nearly prone position, they overestimated body tilt. The subjects could accurately judged body tilt when they were in a nearly supine position. The subject's greatest error in judgement occurred when he attempted to set his body position to 15 degrees forward or backwards from erect. [Ref. 13:pp. 508-510]

A second experiment was performed in which the subject was placed in a totally darkened room and tilted at each of thirteen different pitch orientations. The subject was required to indicate when he perceived that an illuminated target was aligned with his morphological horizon (an imaginary line that runs perpendicular to his body's longitudinal axis and passes through the center of his eyes). The bed used to tilt the subject was the same one used in the first experiment. The subject was placed at each pitch orientation for one minute before the target was illuminated. The experimenter moved the target until the subject told him that the target was now aligned with his (the subject's) morphological horizon. The results indicated that when the subject was tilted at 30 degress forward from the vertical, the subject's set the visual target maximally above the morphological horizon. [Ref. 13:pp. 510-511]

The orientation of the body, and the orientation of the eyes in their sockets, and the locus of retinal stimulation taken together determine visual judgements of spatial orientation. Changes in the subject's position relative to the graviational field affect the otolith-oculomotor reflexes that determine the position of the eyes in their sockets. This affected where the subject judged the target to be. Otolith-oculomotor reflexes do not affect how the subject adjusted his body's orientation in a darkened room. Thus, the positioning of a visual target relative to a subject's body and the positioning of the body to some orientation were different tasks and it was not surprising that the two experimental conditions yielded different results. [Ref. 13:p. 511]

Stoper and Cohen did a series of experiments to determine how different types of information contributed to the judgement of eye level. There are three distinct reference planes relative to eye level: "gravitational referenced eye level" (GREL) given by the gravitational horizontal; "surface referenced eye level (SREL) given by a visual surface; and 'head referenced eye level (HREL) given by a plane fixed with respect to the head. All three eye levels coincide when an observer is standing on level ground in a normal, illuminated terrestrial environment. The experiments performed were designed to separate the relative contributions of each reference system. [Ref. 14:pp. 1-4]

The first experiment was designed to answer the question "What contribution does optical information make to the judgements of GREL?" [Ref. 14:p. 4]. The lights were turned off to eliminate visual information. The subject was seated in a dental chair, and required to set the height of the chair (the chair could be raised or lowered by subject) so that his eyes were level with a small target. The average constants error for the subjects were 0.29 degrees in the light and 2.79 degrees when the room was dark. Thus, the target appeared to be approximately 2.5 degrees higher in the dark than when the room was lighted. [Ref. 14:p. 5]

The interaction of eye level systems was studied by putting them in "conflict" A pitchbox was used to do that. The box was pitched 10 degrees up or down and it pivoted around the subject's eyes. The subject indicated eye level by adjusting a small target's vertical position. There were four within subject factors: viewing conditions (light vs. dark), pitchbox position (6cm separated high vs. low), pitchbox angle (10 degrees down, 10 degrees up, and level), and the target starting position (down vs. up).

When the box was pitched and illuminated and the subject was instructed to set the target to his GREL, judged GREL shifted approximately halfway (mean data had slope of 0.55) toward SREL. [Ref. 14:pp. 7-9]

In another experiment the subject was to set the target with respect to SREL in order to study the effects of gravity on SREL judgements.. The subject stood erected or was placed in a reclining position (reclining on the side eliminated the effect of gravity.) There was a shift in SREL judgements in the direction of HREL (mean data had slope of 0.15) in both the erect and reclining positions. This implied that the gravity/target reference system was not responsible for the bias seen. [Ref. 14:pp. 9-11]

A third experiment studied the effects of reclining verses erect positions in making HREL judgements. The subject's HREL was determined by having the subject set his eye "straight ahead in his head" and then placing a target at his fixation point. The subject was to set a target to his HREL. There was a shift in HREL in the direction of SREL,when the box was illuminated, for both erect and reclining position. The mean data had a slope of 0.45 when the subject stood upright. The mean data had a slope of 0.89 when the subject was reclining. [Ref. 14:pp. 12-13] Thus, gravity is an importance source of information when making judgements about eye level. [Ref. 14:p. 1]

4. The Effect Of Gravity On Hand/Eye Coordination And Spatial Orientation

The effect of acceleration on the relationship between motor action and visual stimulation is a complex one. The acceleration of a particle is defined as the rate of change of its velocity with time. Because the quantity acceleration is a vector, it is characterized by both magnitude and direction. The acceleration of a freely falling body is called the acceleration due to gravity. Its magnitude near the surface of the earth is 9.8 m/s^2 and is directed down to the center of the earth. If an object on the earth is subjected to an acceleration, this acceleration must be combined with the acceleration due to gravity, using vector addition, in order to define the resultant gravitational-inertial forces' magnitude and direction. [Ref. 15:pp. 34-35]

Humans are adapted to the normal terrestrial environment of one-G (9.8 m/s2) and under these conditions signals from the otolith organs are balanced with the proprioceptors in the neck. The apparent position of the visual objects remain relatively stable for different head orientations. When gravitational-inertial fields (GIFs) are altered, this balance is lost and changes in head orientation results in the apparent movement of visual objects. [Ref. 16:p. 318]

In a zero-gravity environment the otoconia in the otolith organs are weightless so that the otolith organs no longer indicate the orientation of the head relative to a reference frame. No reference field is present. The otolith organs are stimulated by efferent neural stimulation of the hair cells and by the acceleration and deceleration caused by head movements. In a hypergravity environment there is an increase in the shearing forces against the hair cells caused by the increased weight of the otoconia in the otolith organs. Because of this increase in the shearing forces, a change in the orientation of the head results in a greater change in the stimulation of the otolith organs than normal terrestrial conditions. [Ref. 1:p. 199]

The altered stimulation to the otolith organs causes an alteration of the resting position of the eyes and the motor impulses to the extrinsic eye muscles required to maintain foveal vision. Visually perceived objects appear to be below their true physical position in a zero-gravity environment and above their true physical position in a hypergravity environment. In the absence of a visual target upon which to fixate, there is a tendency for the eyes to rotate upward in a zero-gravity environment and downward in a hypergravity one. Most people are not aware of these changes in eye position. Alterations in the magnitude of only the gravitational-inertial field results in changes in the apparent location of visually perceived objects which is known as the elevator illusion. [Ref. 1:p. 199]

Changes in the gravitational-interial field produced by acceleration result in altered stimulation of muscle and cutaneous proprioceptors. In the zero-gravity environment, the muscular activity necessary to overcome terrestrial gravity is inappropriate. There is a tendency for the arm to elevate spontaneously and involuntarily. The Golgi tendon organs register reduced tension in muscles. Tension in the muscles result primarily from muscular contractions that are opposed by counteracting forces. The cutaneous proprioceptors are not stimulated by body weight but instead stimulation may result from contact with external surfaces. In hypergravity environment, the body's musculature strains under the increased load. The muscular force needed to overcome terrestrial gravity is no longer sufficient. The Golgi tendon organs register increased tension in the muscles that support the weight of the body. This increased body weight causes additional tensions produced in the antigravity muscles and increased stimulation of cutaneous proprioceptors. [Ref. 1:p. 199]

There is a complex relationship between an intended motor act and its visual, kinaesthetic and proprioceptive consequences which depends upon the gravitational and inertial forces presented when the motor act occurs. Hand-eye coordination is calibrated for normal terrestrial environments. In a zero-gravity environment you would expect a subject to reach too high for a target. However, the target appears lower than its actual physical position due to the elevator illusion Thus, there is a conflict between these two effects. In a hypergravity environment, it is predicted that a man will initially reach too low due to the increased weight of his arm. The target will appear higher than its actual physical position creating a conflict between the motor action and the visual stimulation. [Ref. 16:p. 318]

In one study, eight male subjects were exposed to a 2.0 Gz (force directed in head to foot direction) force in a centrifuge. Each subject repeatedly reached for a mirror viewed target without being able to see his arm. Initially, the subjects reached too low as a result of the mechanical effect of the increased gravity. As the subject continued to make repeated reaching movements, he would reach too high, probably due to the elevator illusion. There were aftereffects of exposure to the 2.0 gravity environment which appear to represent a transient persistence of the recalibrated reaching movement. The aftereffects were present in both the practiced and unpracticed arms, suggesting that there is some central processing instead of only a simple muscular post-contraction phenomenon. It should be noted that there were individual differences between subjects, so more tests should be run. [Ref. 16:pp. 318-322]

In another study, the effect of different intensities of Gz on hand-eye coordination was examined. Three experimental conditions, 1.0, 1.5, and 2.0 Gz were run for each subject. The subjects were unable to see their reaching arm throughout the trials. A baseline was established for each subject at 1.0 Gz each time he was tested in order to reduce session to session variation. During the 1.0 Gz phase the reaching movements tended to cluster around the baseline (mean deviation of 0.06cm). At 1.5 Gz, the reaching movement tended to be well above the baseline (mean deviation of 1.79 cm). There was no significant change as a function of trials in the 1.0 or 1.5 Gz conditions. In the 2.0 Gz environment, initially the subjects reached too low (average 3.99 cm) on the first trial. By the fourth trial, the subjects were reaching above the baseline and overreached for the remainder of the trials. The results suggest that the illusion responsible for overreaching is there at both 1.5 and 2.0 Gz. Correction of the muscle loading effect responsible for the underreaching during the 2.0 Gz condition was due to proprioceptive and kinaesthetic inputs. The initial trajectory of the arm was not what the subjects expected and the subjects were able to compensate for this in the later trials. [Ref. 17:pp. 647-649]

The direction of the accelerating force acting on a body can have important consequences. This acceleration force is vectored with the force of the earth's gravitational field. If the direction of this new force is not parallel to that of gravity, there will be a change in the magnitude and direction of the resultant GIF vector. This can cause both visual and postural illusions, An example of this is the Gx force that a pilot experiences during a catapult launch. The visual or oculogravic illusions causes seen objects to appear to rise above their true physical position. The postural or posturgravic illusion causes the pilot to feel that his body is being tilted backwards. Rotation of the gravitational-inertial acceleration vector relative to the subject causes:

1. a contradictory pattern of stimulation since the semicircular canals indicate that the body is not rotating about a given axis but the otolith organs signal that the subject's orientation is changing relative to the vector
2. a delay in the perception of the changed orientation.

The oculogravic illusion generally reach their maximum value 10-15 seconds after the termination of the accelerative forces and the illusion usually persists for more than 30 seconds. The mean peak magnitude was 6 degrees. The illusion was reported by both experienced pilots and naive subjects. [Ref. 1:pp. 204-210]

II. METHOD

A. INTRODUCTION

A person uses both visual and gravity cues to determine eye level. The orientation of the head with respect to gravity; the orientation of the line of sight with respect to the head; and the orientation of the eye-target line with respect to the line of sight make up the "target/gravity" system. The "target/surface" system can be defined as the system that uses visual surfaces to determine whether the eye-target line is parallel to the ground. A target is considered to be at eye level if the eye-target line, an imaginary line connecting the eye to the target, is parallel to gravitational horizontal. When someone stands on level ground, he/she can use the ground as a reference to determine if a point is at eye level. However, when the environment is pitched or tilted, using the ground as a reference will cause errors in perceived eye level. [Ref. 18:p. 311] It has been shown in experiments that the target/surface system dominates the target/gravity system. Thus, a subject looking into a pitched box will make errors in the direction that the surface is pitched when determining what point is at eye level. A study done by Stoper and Cohen determined that the error the subjects made in judging objective eye level was 0.55 of the pitch angle of the box. [Ref. 14:p. 8]

What effect will this have on a subject's ability to reach out and touch a spot at objective eye level? When reaching out to touch a point, a person receives proprioceptive feedback concerning the position of his/her arm with respect to gravity. Reaching to point at a target at eye level will feel a certain way. Will the subject, while looking at a pitched environment, reach to a point corresponding to perceived eye level or will he/she continue to point to the spot that "feels" like it is at eye level. This study will attempt to define a relationship between where the subject perceives eye level to be and where the subject then points to when the subject is looking into a box that is pitched at different angles.

The experiment was divided into two parts. Part A consisted of the subjects looking into a box that was pitched at angles of approximately 15, 7.5, 0, -7.5, or -15 degrees. The subject was asked to report what number appeared to be at eye level. This established what the subject perceived to be eye level for each of the presented angles. Part B consisted of the subject looking into the box that was pitched at the same five angles as in part A. The subject was given a number that was at objective eye level and was asked to reach out and touch the point on the touchboard that corresponded to that number. At no time was the subject told that the number was at eye level. For this experiment, objective eye level is defined as a line going from the center of the subject's eyes to the scale on the back of the box that is parallel to to the floor of the room and perpendicular to gravity. The difference between where the subject pointed and objective eye level was measured and compared to the results obtained during part A.

It was expected that, during Part A, the subjects would select a number that is above objective eye level, when the box is pitched with an upward slope towards the back, i.e., at positive angles; at objective eye level when the box is level (bottom and top of the box are parallel to the floor of the room), i.e., for an angle of 0 degrees ; and below objective eye level, when the box is pitched with a downward slope toward the back, i.e., at negative angles. How does the angle at which the box is pitched at influence the subject's pointing response? If, when the box is pitched at various angles, the subject could point to the spot on the touchboard that corresponds to the number told him/her (i.e., a number at objective eye level), then the pitch angle of the box does not influence the subject's response. If the subject points to a spot below objective eye level when the box is pitched upward (i.e., positive pitch angles), or to a spot above objective eye level when the box is pitched downward (i.e., negative pitch angles), then the pitch of the box does influence the subject's response. For example, if in part A, when the box was pitched at +15 degrees, the subject's perceived eye level was above objective eye level, then when the subject was told a number during part B that was at objective eye level, the number would appear to be below eye level to the subject. Therefore, the subject's pointing response would be expected to be below objective eye level.

B. SUBJECTS

Ten right-handed subjects, 5 males and 5 females, participated in the experiment. Their ages ranged from 17 to 46 years.

C. APPARATUS

The equipment (see Figure 1) consisted of a box surrounded by a wooden frame, a pair of goggles fixed to the frame, a wooden touch board and a moveable stool. The interior of the box was white. It was lighted by ambient room illumination. The box's dimensions were: 35.6cm (14in) long by 28cm (11in) wide by 52cm (20.5in) high. The front of the box was open. A wooden frame measuring 51cm (20in) long, 76cm (30in) wide, and 91.5cm (36in) high surrounded the box. A 76 cm (30in) wooden crossbeam was placed horizontally across the front of the frame. A metal rod was placed horizontally on the frame, at the center, behind the back wall of the box. The rod passed through metal rings on the back of the box and served as the pivot point for the various pitch angles.

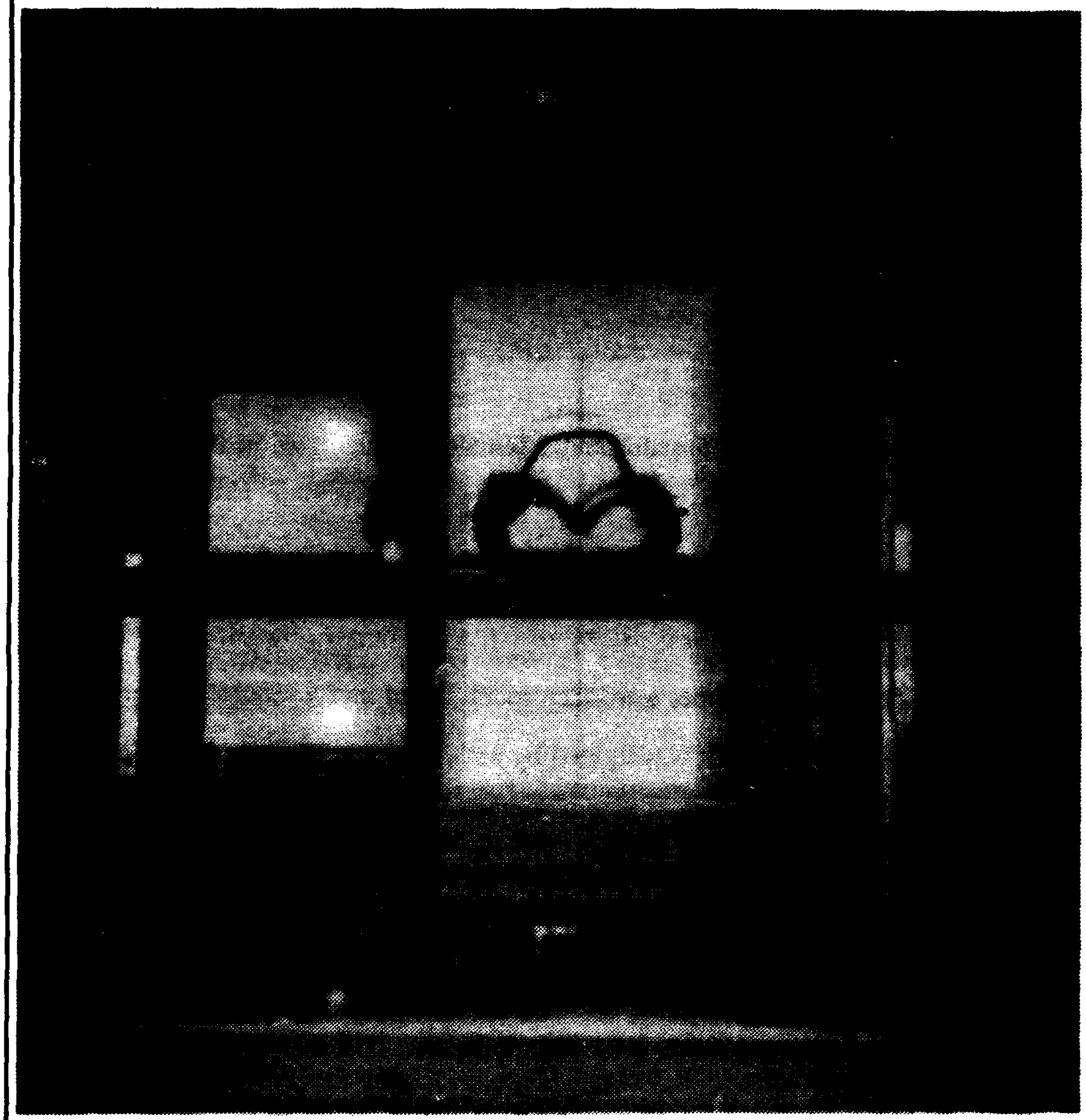

Figure 1. Experimental Apparatus

Thus, the box rotated around its rear at the objective eye level of the subject. The pitch angle was defined: plus (+) was back higher than front and minus (-) was back lower than front.

The goggles were fixed to the wooden 76cm crosspiece so that the center of the goggles was aligned with the center of the box when the box was oriented at a 0 degree pitch angle. The subject could view the entire interior of the box at all pitch angles.. To keep the actual level of the eyes constant throughout the experiment and across subjects, the height of the stool was adjustable.

The touchboard was made of 0.5in plywood. It was 23cm (9in) wide by 91.5cm (36in) high and was attached to the right back of the frame in front of the horizontal metal rod. The horizontal distance between the subject's eye and the plane of the touchboard is 48cm (19in). Graph paper was used to record the subject's pointing responses. A straight edge attached to the front of the touchboard and a line corresponding to the horizontal rod were used to align the graph paper.

Two plywood obstruction screens with dimensions of 46cm (18in) long by 91.5cm (36in) high were placed along both sides of the box to fill the 13cm (5in) gap between the front of the frame and the side of the box. A 23cm (9in) by 46cm (18in) cloth screen was hung from a piece of wood attached to the right obstruction screen and the crosspiece to ensure that the subject did not see his/her hand when he/she pointed to the touch board

A numerical paper scale was placed along the back center of the box and passed through slits cut in the top and bottom of the box. The ends of the scale were taped together, forming one continuous, adjustable loop. The scale was sequentially numbered and the numbers were separated by 0.25 inch. A line drawn on the back of the box was used to align the scale so that a given number could be set at objective eye level.

A bolt assembly was attached to the right obstruction screen and five holes were drilled on the right side of the box in an arc corresponding to each of five angles of approximately, 15, 7.5, 0, -7.5, -15 degrees. When one of these holes was aligned with the bolt, the box was pitched to the desired angle and remained stationary.

D. PROCEDURE

Prior to the start of the experiment, the subject was handed a pen and asked to reach out and make a mark on a piece of paper hung on a wall to determine if he/she normally points with his/her right/left hand. Only right handed subjects were selected for this experiment.

Before collecting any data, the order in which the pitch angles were to be presented was recorded. Each angle was presented one time for part A and one time for Part B. The pitch angles were presented using a counter balanced order (Latin square design) across subjects. This ensured that every combination of angles was presented. The order of presentation of the angles in Part B corresponded to the order of presentation of the angles in Part A. The number scale was changed a predetermined amount after every trial to ensure that the subject did not use it as a visual cue. A piece of 17 inch grid paper was attached to the touchboard and aligned so that the center of the paper corresponded to objective eye level.

The subject was shown the experimental apparatus and the touchboard was pointed out. The subject was seated on the stool, which was then adjusted so that the subject could comfortably rest his/her face against the goggles. The experimenter read the instructions for the part of the experiment that the subject did first. (See Appendix A). Half the subjects did part A first and the other half did part B first. A practice session was undertaken prior to reading the instructions for part B. The subject was then asked to place his/her face against the goggles in such a way that the subject's head was vertical. An elastic strap was placed around the subject's head and he/she was reminded to keep his/her head stationary throughout the experiment. Each trial of part A consisted of the following:

1. The subject was asked to close his/her eyes for 15 seconds. During this time, the scale was changed by a recorded, predetermined amount.
2. The subject was asked to open his/her eyes and look into the box. After 15 seconds, the subject reported what number appeared at eye level.

After five trials, the pitch of the box was changed by a predetermined amount,and the procedure was repeated until data were collected at all five angles of the box. (See Figure 2)

Part B required a practice session to ensure that the subjects pointed correctly. The subjects were trained to make only a single point with the tip of the pen and to bring their right hand back so that it rested on the bottom right corner of the frame. They were instructed to make the reaching motion a rapid and smooth one. Each trial of Part B consisted of the following :

1. The subject was asked to close his/her eyes for 15 seconds. During this time, the scale was changed a recorded, predetermined amount.
2. The subject was asked to open his/her eyes and look into the box for 15 seconds. He/ she was then told a number (This number was at objective eye level).
3. The subject was asked to imagine a horizontal line going from the number to the touchboard, and to reach out and point to the spot where that imaginary line intersected the touchboard. After five trials, the pitch of the box was changed a predetermined amount. The subject was handed a new pen, with a color that corresponded to the new pitch angle, and the procedure was repeated until data were collected at all five pitch angles. (See Figure 3)

Figure 2. Subject Making Verbal Judgment

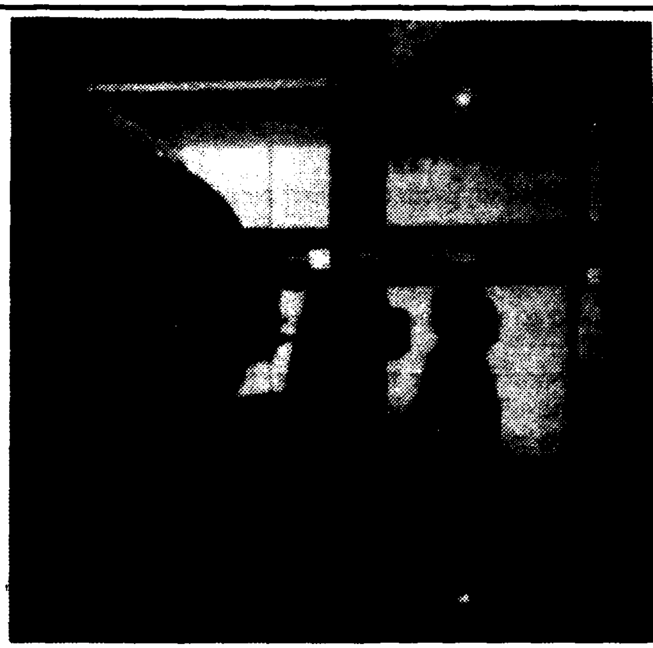

Figure 3. Subject Making Pointing Response

E. DATA COLLECTION

To determine a subject's error in judging eye level, it was necessary to know what number was at objective eye level. A vertical number scale was positioned along the back inside of the box. The numbers were sequential and separated by 0.25 in. A number was aligned with a point on the back outside of the box. There were 48 numbers between a number aligned at that mark and a number at objective eye level when the box was at a 0 degree angle. Because 1.5 in. separated the actual pivot point from the scale, the distance between the mark on the back of the box and objective eye level was not constant for all angles. The geometry and calculations for this effect are shown in section 1 of Appendix B.

During part A of the experiment, the subject reported the number that appeared to be at eye level. This number was subtracted from the number that was at objective eye level and divided by four to give the numerical difference in inches. Two equations were used to calculate the experimental error in degrees. The first equation was used to find y: (See Figure 4)

$$y = (x2 + z2 - 2xz\cos Y)0.5$$

where:

y equals the linear distance from the subject's eye to the number identified as appearing to be at eye level.

x is the linear distance between objective and subjective eye level.

P was the pitch angle of the box. P was positive when the box was pitched with an upward slope towards the back. P was negative when the box was pitched with a downward slope towards the back.

Y equals 90 minus P when: P and x are both positive or negative.

Y equals 90 plus P when: P is positive and x is negative or P is negative and x is positive.

z equals the distance from the subject's eyes to the point on the scale corresponding to objective eye level. Because there was 1.5 in between the pivot point and the scale, z was different for each angle. The geometry and calculation to determine z are shown in section 2 Appendix B.

The error in degrees, angle X, was then found using the equation:

$$X = \sin^{-1}[(x \sin Y)/ y]$$

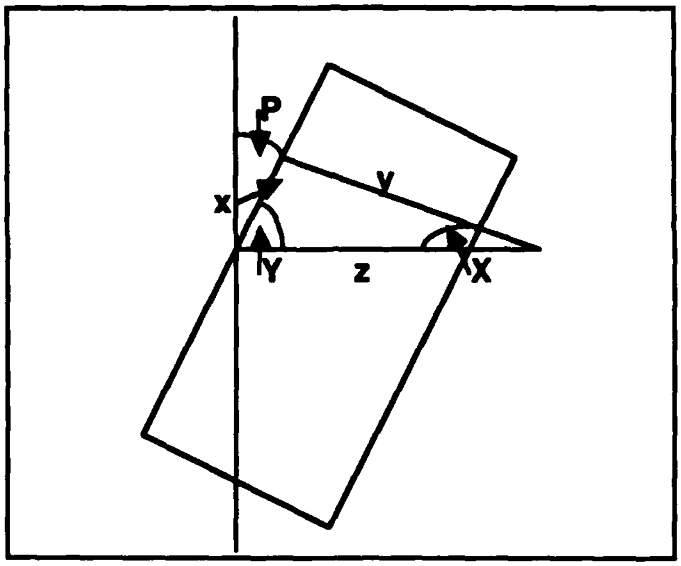

Figure 4. Variable Defination Used For Conversions From Inches To Degrees

To determine the error that the subject made during part B of the experiment while attempting to point to objective eye level, the difference between the mark made by each pointing response and objective eye level was measured. A correction was made to account for the fact that the touchboard was fixed so that it did not exactly correspond to the scale when the box was pitched. The geometry and calculations for these corrections ar shown in section 3 of Appendix B. Once the corrections were made, the error in degrees, angle X' was calculated using:

$$X' = \tan^{-1}(x'/h)$$

where:

x' equals the corrected numerical error

h equals the distance from the subject's eyes to the touchboard. (19 in)

The mean and standard deviation for each subject's pointing error were calculated (Appendix C). The results were graphed separately for each subject (Appendix D). The mean and standard deviation of all the subject's verbal and pointing errors were calculated and graphed.

III. RESULTS

The mean verbal and pointing errors for each individual subject and for all ten subjects are presented in Table 1.

An ANOVA was performed on the verbal judgement and pointing error data, and a summary of the results are presented in Table 2. The ANOVA shows a highly significant effect (<.001) of pitchbox angle for the verbal judgement errors ($F(4,36) = 50.14$) and the pointing errors ($F(4,36) = 21.47$).

The verbal judgement error pitch X trial interaction reaches statistical significant (<.05; $F(16,144) = 2.13$). But this factor accounts for less than one percent of the variance, so this interaction has no practical significance.

A regression analysis was performed on the means for each subject's individual data and the group data to determine the mean slopes, y-intercepts, and r^2-values for the data. The results are shown in Table 3. The individual subject's data is graphed and presented in Appendix D.

The data for all ten subjects' mean verbal and pointing errors, when graphed, can be fitted to by a straight line. The mean verbal judgements have a slope of 0.48 with an r^2-value of 0.983. An r^2-value that close to one signifies that the function is linear. The slope is -0.19 for the subjects' mean pointing errors with an r^2-value of 0.997, again signifying a linear function. (See Figure 5)

The mean verbal judgements for seven of ten subjects (LS1, LS2, LS3, LS4, LS5, LS6, and LS8) had slopes of between 0.42 and 0.53. All of these subjects had r^2-values over 0.83 signifying the function is linear. Another subject's (LS9) mean verbal judgement

TABLE 1
MEANS OF SUBJECT'S JUDGEMENT ERROR IN DEGREES

ANGLES SUBJECTS	-15	-7.5	0	7.5	15
LS1 VERBAL	-10.74	-7.89	-5.32	-1.25	1.53
LS1 POINTING	0.62	1.11	-3.04	-1.87	-6.16
LS2 VERBAL	-5.76	-4.08	-0.94	5.18	9.44
LS2 POINTING	-4.86	-4.52	-5.94	-7.77	-9.43
LS3 VERBAL	-1.68	-2.03	1.88	9.15	12.36
LS3 POINTING	-0.68	-0.63	-3.85	-6.12	-7.51
LS4 VERBAL	-7.35	-4.08	-O.94	3.92	4.97
LS4 POINTING	-3.38	-6.08	-6.02	-5.44	-5.94
LS5 VERBAL	-10.90	-9.30	-5.94	3.92	1.25
LS5 POINTING	0.86	3.42	1.08	-1.89	-4.79
LS6 VERBAL	-9.44	-6.14	0.63	3.60	3.72
LS6 POINTING	-6.03	-8.43	-8.77	-9.97	-11.20
LS7 VERBAL	-7.99	-3.92	-0.16	1.09	-1.84
LS7 POINTING	-4.14	-3.86	-4.43	-5.04	-8.41
LS8 VERBAL	-5.60	-0.16	4.23	7.25	7.84
LS8 POINTING	1.44	-2.78	-5.45	-7.29	-4.35
LS9 VERBAL	-16.11	-9.30	-1.72	5.66	11.06
LS9 POINTING	2.09	-0.63	-3.35	-7.23	-6.02
LS10 VERBAL	0.76	2.66	4.39	6.77	11.71
LS10 POINTING	-10.99	-16.12	-15.10	-17.20	-17.61
MEAN VERBAL	-7.48	-4.42	-0.39	4.53	6.20
MEAN POINTING	-2.51	-3.85	-5.49	-6.98	-8.14

TABLE 2
SUMMARY OF ANOVA

	SUMSQ	DF	MSQ	F-RATIO	P(H0)	%VARIANCE
VERBAL						
PITCHBOX ANGLE	6709.97	4	1677.49	50.14	<0.001	62.81%
TRIALS	4.07	4	1.02	1.03	N.S.	0.04%
P X T	25.37	16	1.59	2.13	<0.05	0.24%
SUBJECTS	2595.89	9	288.43	----	-----	24.30%
S X P	1204.51	36	33.46	----	-----	11.28%
S X T	35.59	36	0.99	----	-----	0.33%
S X P X T	107.33	144	0.75	----	-----	1.00%
TOTAL	10,682.73	249	100.00%			
POINTING						
PITCHBOX ANGLE	1040.16	4	260.04	21.47	<0.001	16.58%
TRIALS	21.10	4	5.28	2.47	N.S.	0.34%
P X T	43.97	16	2.75	0.70	N.S.	0.70%
SUBJECTS	4090.24	9	454.57	----	-----	65.18%
S X P	436.00	36	12.11	----	-----	6.95%
S X T	76.54	36	2.14	----	-----	1.23%
S X P X T	566.57	144	3.93	----	-----	9.03%
TOTAL	6274.97	249				100.00%

data had a slope of 0.92 suggesting almost complete capture by the pitched visual field. The r^2-value was 0.997, so this function is also linear.

TABLE 3
REGRESSION ANALYSIS RESULTS

	VERBAL			POINTING		
SUBJECT	SLOPE	Y-INTER-CEPT	R^2 VALUE	SLOPE	Y-INTER-CEPT	R^2VALUE
LS1	0.42	-4.73	0.994	-0.22	-1.87	0.785
LS2	0.53	0.77	0.961	-0.16	-6.51	O.896
LS3	0.52	3.93	0 .909	-0.26	-3.76	0.942
LS4	0.44	-0.70	0.976	-0.06	-5.37	0.386
LS5	0.50	-4.20	0.830	-0.22	-0.26	0.694
LS6	0.48	-1.53	0.913	-0.16	-8.88	0.947
LS7	0.23	-2.56	0.588	-0.13	-5.18	0.683
LS8	0.46	2.71	0.929	-0.21	-3.69	0.593
LS9	0.92	-2.08	0.997	-0.30	-3.03	0.888
LS10	0.35	5.26	0.944	-0.19	-15.41	0.727
MEAN	0.48	-0.31	0.983	-0.19	-5.59	0.997

The ninth subject's (LS10) mean verbal judgement had a slope of 0.35 and an r^2-value of 0.944, indicating a very consistent but weak linear function. The last subject's mean verbal judgements had a slope of 0.23, with an r^2-value of the verbal judgements was 0.58, so this function was neither strong nor linear. The visual field did not have as great an effect on these subjects' judgements as on the other 8 subjects.

Thus, the data for individual subjects approximately followed the trends of the group, though there were variations. The y-intercept equation for the slope of all subjects' mean verbal judgements is:

Verbal Judgement Error = 0.48(Pitch Angle In Degrees) - 0.31

Six of the subjects (LS1, LS2, LS5, LS6, LS8, LS10) had mean pointing responses that had slopes between -0.16 and -0.22. Four of those subjects (LS1, LS2, LS6, LS10) had r^2-values above 0.70 and the other two subjects (LS5, LS8) had r^2-values above 0.59, so all functions were roughly linear. One subject's (LS7) mean pointing responses had a slope of 0.13 and an r^2-value of 0.683, and another(LS4) had a slope of -0.06 and an r^2 of 0.384 suggesting that the effect of the pitched visual field was not as powerful. The slope of LS4's data was extremely small. LS3's mean pointing responses had a slope of -0.26 and an r^2-value of 0.942, indicating a linear function. LS9's mean pointing response slope is -0.30, which is the largest of any of the subjects and the function is linear (r^2-value of 0.89).

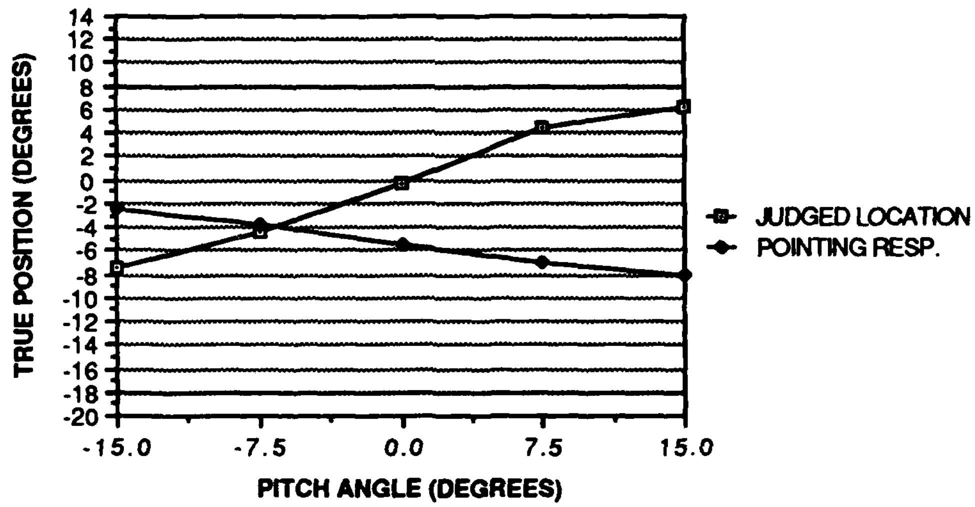

Figure 5. Mean Apparent Eye Level as a Function of Pitch Box Angle

The data for individual subjects again approximately followed the trends of the group, though there was more varibility in pointing response than there was for verbal judgements. Subjects consistently pointed below objective eye level (mean intercept was -5.59 degrees). During the practice session with the box pitched at 0 degrees, every subject initially pointed too low. With feedback, they were able to point to eye level after several tries. However, during the experiment, when the box was pitched at 0 degrees the mean pointing error for all subjects was -6.15 degrees.

The y-intercept equation for the slope of all subjects' pointing responses in degrees is:

Pointing Error = -0.19(Pitch Angle In Degrees) - 5.39

The magnitude of the slope of the mean pointing error is approximately 50 percent of the magnitude of the mean verbal judgement error. As expected, the direction of the mean pointing error is opposite that of the mean verbal error and the angle of pitch of the box. The slopes of the graphs of subject LS9's mean verbal judgement data and mean pointing response data were the greatest obtained for any of the subjects. The slope of the graph of subject LS7's mean verbal judgement was the shallowest of any of the subjects and the slope of his mean pointing responses was considerably less than the mean group slope. This suggest that there is a correlation between mean verbal judgement and mean pointing responses.

The regression of the pointing errors on judgements error yields an equation that can be used to approximately predict where a person will point in degrees given that person's verbal judgement error in degrees. The new equation is:

Pointing Error = -0.47(Verbal Judgement Error) - 5.54

It should be noted that this equation applies to angles between plus and minus 15 degrees. Larger pitch angles were not tested.

IV. DISCUSSION

A. GENERAL DISCUSSION OF RESULTS

A person looking at a visual field that is pitched at some angle will make an error in judgement that changes at a rate of 48 percent of that angle, and is in the same direction as the angle. The error made in pointing changes at rate of 19 percent of the angle in the direction opposite that of perceived eye level.

Objective eye level remained constant throughout the experiment. Because the subject kept his/her head approximately stationary throughout the experiment, the number that was viewed at objective eye level would have been at the same retinal location throughout all trials, if the subject maintained a constant angle of gaze. It was the surrounding visual field that influenced what the subject ultimately perceived to be eye level, not a change of the optic path.

As expected, the direction of the error in pointing response was opposite to that of the verbal judgement, which represents the subject's perception of eye level. If, for example, the pitch angle of the box was negative (downward slope toward the back of the box), the subject perceived that a number was at eye level, when in fact, that number was below objective eye level. The number the experiment gave the subject (the number at objective eye level) would appear to be above eye level to the subject. Thus, he would point too high.

The magnitude of the pointing error was only 48 percent of the perceptual error. It might be expected that the magnitude of the perceptual error and pointing error would be the same. Why were there discrepancies in the magnitudes? At no time were the subjects informed that the number the experimenter told them was at eye level, though some subjects who had done the verbal judgement first did guess that this was the case . The subject received feedback from proprioceptive receptors concerning the position of his/her arm. However, if the subject did not realize that he/she was to point to the same location on every trial, this information received from the proprioceptors may not have been useful across angles. It could be used for all pointing response done within the trials for each angle, since for those five trials, the number the subject was using to decide where to point to remained the same. Feedback from the proprioceptors, not visual information alone, may have determined where the subject pointed to and may have limited the errors in pointing that might otherwise might have occurred.

The subjects were not very successful at pointing to eye level when they could not see their hand. During the practice session, all the subjects initially pointed too low, though with feedback, they were able to point to eye level after several tries. However, during the experiment, when the box was pitched at zero degrees, the subjects' mean pointing error was -6.15 degrees. It appears that pointing to eye level without observing the hand is a motor task that the subjects are not accustomed to performing accurately. The motion of pointing to eye level required the subject to point slightly upwards, not straight out, and sideways, not straight ahead. The touchboard was positioned at the end of most subject's reach. These factors might have affected their pointing. Additionally, the board was fixed and did not change when the box was pitched. When the box was pitched, some of the numbers were closer to the subject and some were further away. Some subjects reported that, when they went to point to the touchboard, it was not located where they expected it to be; it was either too close or too far away.

More research should be done in this area. How would larger angles affect perception and pointing errors? How would left-handed subjects, using their nonperferred hand perform? What would happen if the subject was pitched in the same direction as the visual field, or in the opposite one? What is the effect of an altered gravitational field when the visual field, observer, or both are pitched? How long do these errors last when the subject is no longer looking at a pitched environment? These questions are beyond the scope of this thesis, but should be pursued.

B. APPLICATIONS

People regularly work in environments where the visual field is pitched. Sailors on ships, submariners, pilots of aircraft, astronauts in spacecraft and even drivers of automobiles, all experience, at least part of the time, pitched visual fields. Take for example, a pilot of a small aircraft who is crop-dusting a field located at the bottom of some hills. Even when the aircraft is level, if it is approaching the hills, the pilot will see an environment that is pitched up or down. The results of this experiment suggest that the pilot is likely to make errors in judgement when trying to determine an obstacle's location relative to himself and the aircraft. If the hill slopes in an upward direction, an object (i.e., powerlines) that is located at the pilot's objective eye level may appear to the pilot to be located below his eye level. This erroneous perception by the pilot may mean that the corrections made to avoid the obstacle will not be great enough to miss the object.

A pilot of a tactical aircraft flying a low level mission over some hills is flying a speed much greater than that of the crop-duster, reducing the time available to correct for any errors in judgement. Additionally, during combat missions, these pilots may be flying over hostile terrian, requiring even greater vigilance. A tactical pilot is likely to make errors in visual judgements, if he is asked to judge the location of himself and his aircraft relative to some target located on a hill. If the hill is sloped downward, the pilot is likely to make a judgement that places a target at a location above where it actually is. This may lead to a targetting error if the pilot has to depend on his visual judgement alone. Using Instruments is a way to avoid making targetting errors based on faulty human visual perception.

Another error may occur if the pilot has to make unseen reaching movements in order to arm or fire a weapons system. The results of the experiment suggest that a pilot approaching a hill sloped downward will reach too high relative to where he would reach in an environment where the visual field is not pitched. If it is critical that no error is made by the pilot, then the switch should be located in such a way that an error is very unlikely to occur. Placing the control on the stick or throttle is one method of getting rid of the pointing error. However, there is a limit to how many switches can be placed on the stick and throttle. Another method is to have the pilot look at what he is pointing to, though the amount of time that a pilot can afford to be looking inside the cockpit, instead of out, is very limited. If the switches cannot be placed on the stick or throttle, they should be spaced as far apart as is possible and shaped or contoured in such a way that the pilot can determine by touch if he has made an error so that he can correct for it.

In space, the problems will probably be greater since the orientations of the spacecraft and astronauts are not fixed. There is no gravitational field to establish up or down. Astronauts have a freedom of movement that is not available under terrestrial conditions. Errors are likely to occur if an astronaut must judge the location of an object, control or display relative to his/her own body, and he/she is not aligned with it the same way every time. Fasteners can be used to keep an astronaut positioned in front of critical displays or controls. This would allow the astronauts to view the displays at the same angle every time. Displays should be clearly marked to reduce the chance of the astronaut reading the wrong display.

The pitched field orientation encountered in space is also likely to cause an astronaut to make errors in reaching, if he/she is not watching his/her hand. Controls should be spaced as far apart as possible. Labels should be clear and different shapes should be used for the controls. However, as in an aircraft, space is limited on the control panels of spacecraft.

Both spacecraft and tactical aircraft operate in environments where the gravitational field varies. An altered gravitational field causes errors in a person's perception of eye level and in his/her pointing responses. It is possible that this will make a person's judgements of eye level even more inaccurate when a pitched visual field is present. Once an astronaut is in orbit, the gravitational field, though different from that of earth, will be virtually absent (i.e., micro-G). This should allow an astronaut to adapt to the relatively constant, new conditions. However, a tactical aircraft may experience a rapidly changing gravitational field. Thus, it is important for pilots and astronauts to depend on instruments to give themselves information concerning the vehicle's true postion relative to objects.

APPENDIX A. INSTRUCTIONS

1. PART A

You will keep your eyes closed until asked to open them. At that time you will look for 15 seconds into a box that will be pitched at different angles. I will ask you to tell me what number appears to be at eye level. To determine eye level imagine a line going from the center of your eyes to the back of the box that is parallel to the floor of the room and perpendicular to gravity. Please report a number. If you think eye level falls between two numbers, tell me the number that is closest to what you think is eye level. I will then ask you to shut your eyes again. The number scale in the back will be changed so that you can not use the number as a cue for determining eye level. After five trials, the angle of the box will be changed. Please try to keep your head still throughout the experiment. You will be asked to make 25 judgements under these conditions. Do you have any questions?

2. PART B PRACTICE

I am going to hand you a pen. I want you to position your hand so that it rests on the bottom right corner of the frame. I am going to tell you a number. I want you to imagine that there is a horizontal line going through the number to the touchboard on the right. I want you to rapidly, with one motion, to reach out and touch the touchboard where the imaginary horizontal line intersects it. You should only make a single mark with the tip of the pen. You should then bring your hand back so that it once more rests on the bottom right corner of the frame. You will be allowed to look at where you pointed to and I will tell you whether you pointed too high, too low or at the point. I will have you repeat this five times.

3. PART B EXPERIMENT

You will keep your eyes closed until asked to open them. At this time you will look for 15 seconds into a box that will be pitched at different angles. I will tell you a number. I want you to imagine that there is a horizontal line going from the middle of that number to a point on the touchboard to your right. I want you to reach out, using a smooth, rapid motion and touch a spot on the touchboard that corresponds to where the horizontal line intersects the touchboard. Please try to make only a single point with the pen and bring your hand back until it rests on the bottom right corner of the frame. I will then ask you to close your eyes again. After five trials, the pitch angle of the box will be changed. Please try to keep your head still throughout the experiment. You will make a total of 25 reaching responses. Do you have any questions?

APPENDIX B. DATA CALCULATIONS

1. CORRECTIONS FOR DETERMINING NUMBER AT OBJECTIVE EYE LEVEL

The scale that the subjects saw was a series of sequential numbers. Each number is separated by 0.25 inch. A number was aligned with a line on the back of the box. There are 48 numbers between a number aligned at that line and the number at objective eye level when the box is at a 0 degree angle. A correction must be made for the other angles due to the fact that there is 1.5 inches between the actual pivot point and the scale.

The equation:

$$f = \frac{d(1-\cos P)}{\sin P}$$

where:

f equals the linear distance between where a number would appear when the box is pitched at 0 degrees and where the number appears when the box is pitched to a different angle.

d equals 1.5 inches

P is the pitch angle of the box

will make the correction (See Figure 6). To determine the how many numbers there were between the number at eye level and the number aligned with the line on the back of the box, f/.25 is used, and rounded to the nearest 0.5 . This number was then subtracted from 48. (See Table 4)

For angles of 7.5 and -7.5 degrees, a space between two numbers rather than a number was aligned with the line on the back of the box. This ensured that there was a number, not a space, at objective eye level.

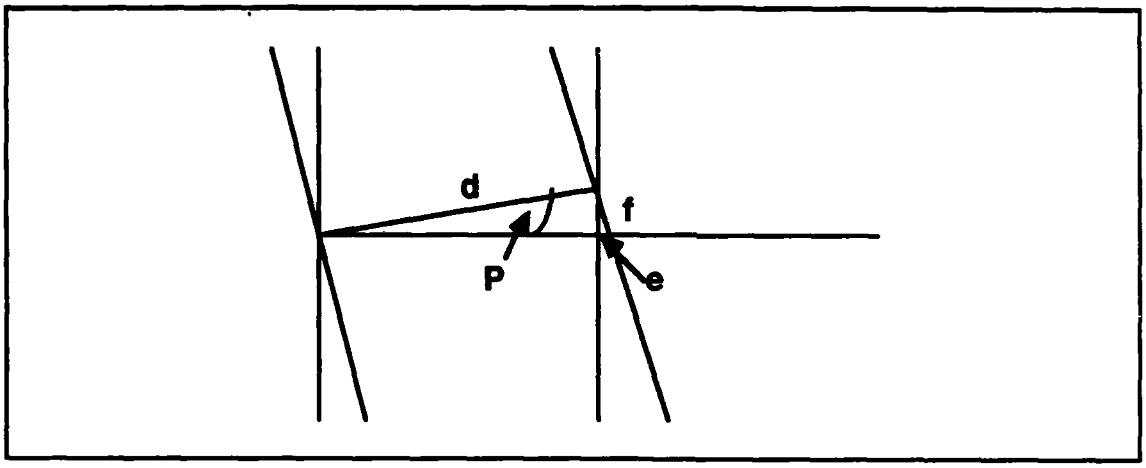

Figure 6. Definations Of Variables Used to Calculate e And f

TABLE 4. CORRECTIONS TO SCALE

ANGLE	f	f/0.25	48-f/0.25
-15	0.40	-1.0	49.0
-7.5	-0.20	-0.5	48.5
0	0	0	48
7.5	0.20	0.5	47.5
15	0.40	1.0	47

2. CALCULATION OF DISTANCE z

The distance z was equal to 18.25 in when the box was pitched at 0 degrees. However, since the actual pivot point was different from the point on the scale at eye level it is necessary to correct z by subtracting e from it. (See Figure 6)

To calculate e the equation:

$$e = \frac{d(1-\cos P)}{\cos P}$$

is used. For the angles 7.5 and -7.5, e equals .013 so z equals 18.24. For the angles 15 and -15 e equals .053 making z equal 18.20

3. CALCULATIONS TO CORRECT FOR A FIXED TOUCHBOARD

A correction was made to account for the fact that the touchboard was fixed so that it did not exactly corresponds to the scale when the box was pitched. The equations used to make the correction are:

$$r = (x\tan P + d)\sin P$$

$$x' = x - r$$

where:

r equals the correction factor
x equals the measured pointing error
P equals the pitch angle
d equals the distance from the back of the box to the position to the number scale.
x' equals the corrected pointing error

(See Figure 7)

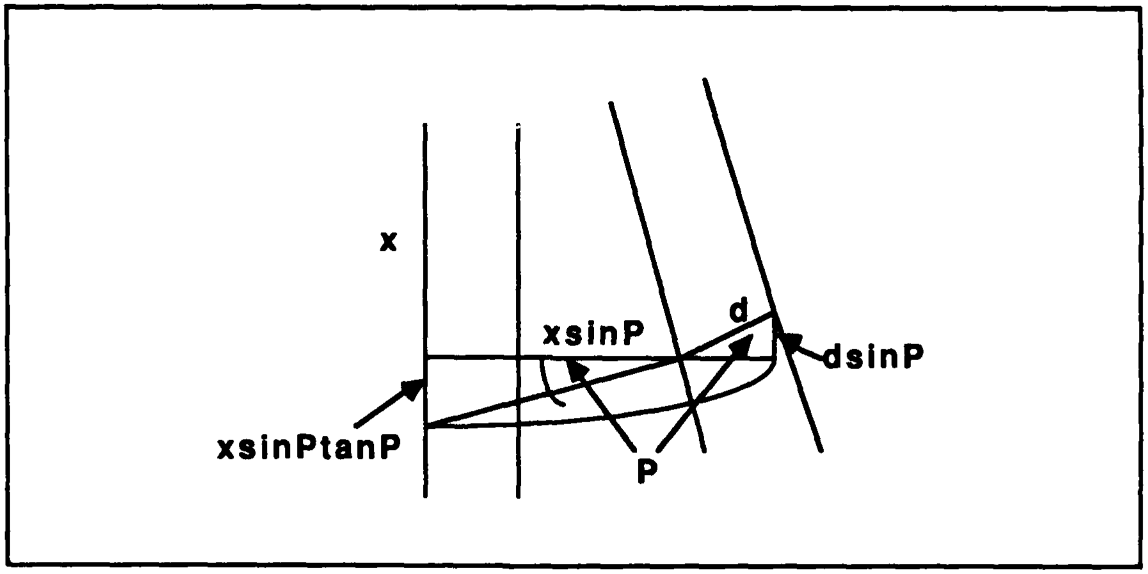

Figure 7. Definations of Variables Used To Calculate z

APPENDIX C. INDIVIDUAL DATA

TABLE 5 INDIVIDUAL VERBAL JUDGMENTS - RAW DATA IN 1/4 INCH S
[DEVIATION FROM EYE LEVEL - MINUS IS BELOW, PLUS IS ABOVE
BOX TILT ANGLE DEGREES - PITCH UP (BOTTOM RISES AT BACK) IS

SUBJECT: LS1

PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	-14	-9	-7	-2	2
	2	-12	-10	-8	-1	2
	3	-14	-11	-7	-2	2
	4	-14	-10	-6	-1	2
	5	-14	-10	-6	-2	2
MEAN		-13.60	-10.00	-6.80	-1.60	2.00
SDEV		0.80	0.63	0.75	0.49	0.00

SUBJECT: LS2

PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	-8	-5	-1	6	13
	2	-7	-5	-2	5	11
	3	-7	-5	-1	7	11
	4	-8	-5	-1	7	13
	5	-7	-6	-1	8	12
MEAN		-7.40	-5.20	-1.20	6.60	12.00
SDEV		0.49	0.40	0.40	1.02	0.89

SUBJECT: LS3

PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	-1	-2	3	10	17
	2	-2	-2	2	9	15
	3	-2	-3	3	13	15
	4	-3	-3	1	12	16
	5	-3	-3	3	14	15
MEAN		-2.20	-2.60	2.40	11.60	15.60
SDEV		0.75	0.49	0.80	1.85	0.80

SUBJECT: LS4

PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	-9	-6	-1	6	6
	2	-10	-4	-2	4	7
	3	-10	-5	0	5	6
	4	-9	-5	-2	5	6
	5	-9	-6	-1	5	7
MEAN		-9.40	-5.20	-1.20	5.00	6.40
SDEV		0.49	0.75	0.75	0.63	0.49

SUBJECT: LS5						
PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	-12	-10	-6	3	5
	2	-11	-12	-9	5	7
	3	-14	-12	-8	5	0
	4	-16	-12	-7	5	-2
	5	-16	-13	-8	7	-2
MEAN		-13.80	-11.80	-7.60	5.00	1.60
SDEV		2.04	0.98	1.02	1.26	3.72
SUBJECT: LS6						
PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	-14	-10	1	4	8
	2	-12	-8	-1	4	4
	3	-12	-8	2	5	2
	4	-13	-7	1	5	6
	5	-9	-6	1	5	4
MEAN		-12.00	-7.80	0.80	4.60	4.80
SDEV		1.67	1.33	0.98	0.49	2.04
SUBJECT: LS7						
PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	-9	-4	1	1	-2
	2	-9	-5	-1	2	-1
	3	-10	-5	0	2	-2
	4	-12	-6	0	1	-3
	5	-11	-5	-1	1	-4
MEAN		-10.20	-5.00	-0.20	1.40	-2.40
SDEV		1.17	0.63	0.75	0.49	1.02
SUBJECT: LS8						
PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	-7	-1	5	10	8
	2	-7	0	5	9	10
	3	-7	0	6	10	11
	4	-8	0	5	9	11
	5	-7	0	6	8	10
MEAN		-7.20	-0.20	5.40	9.20	10.00
SDEV		0.40	0.40	0.49	0.75	1.10

SUBJECT: LS9

PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	-20	-11	-1	8	14
	2	-19	-11	-3	7	14
	3	-20	-12	-3	8	13
	4	-21	-13	-2	7	14
	5	-21	-12	-2	6	15
MEAN		-20.20	-11.80	-2.20	7.20	14.00
SDEV		0.75	0.75	0.75	0.75	0.63

SUBJECT: LS10

PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	-1	4	6	10	16
	2	1	3	6	7	15
	3	3	3	6	9	15
	4	1	4	5	9	14
	5	1	3	5	8	14
MEAN		1.00	3.40	5.60	8.60	14.80
SDEV		1.26	0.49	0.49	1.02	0.75

TABLE 6 INDIVIDUAL VERBAL JUDGMENTS - DATA IN DEGREES
(DEVIATION FROM EYE LEVEL - MINUS IS BELOW, PLUS IS ABOVE.
BOX TILT ANGLE DEGREES - PITCH UP (BOTTOM RISES AT BACK) IS

SUBJECT: LS1

PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	-11.06	-7.09	-5.48	-1.56	1.53
	2	-9.44	-7.89	-6.25	-0.78	1.53
	3	-11.06	-8.67	-5.48	-1.56	1.53
	4	-11.06	-7.89	-4.7	-0.78	1.53
	5	-11.06	-7.89	-4.7	-1.56	1.53
MEAN		-10.74	-7.89	-5.32	-1.25	1.53
SDEV		0.65	0.50	0.58	0.38	0.00

SUBJECT: LS2

PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	-6.24	-3.92	-0.785	4.71	10.25
	2	-5.44	-3.92	-1.57	3.92	8.64
	3	-5.44	-3.92	-0.785	5.5	8.64
	4	-6.24	-3.92	-0.785	5.5	10.25
	5	-5.44	-4.71	-0.785	6.29	9.44
MEAN		-5.76	-4.08	-0.94	5.18	9.44
SDEV		0.39	0.32	0.31	0.81	0.72

SUBJECT: LS3						
PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	-0.763	-1.56	2.35	7.89	13.5
	2	-1.53	-1.56	1.57	7.09	11.87
	3	-1.53	-2.35	2.35	10.25	11.87
	4	-2.3	-2.35	0.785	9.46	12.69
	5	-2.3	-2.35	2.35	11.04	11.87
MEAN		-1.68	-2.03	1.88	9.15	12.36
SDEV		0.58	0.39	0.63	1.46	0.65
SUBJECT: LS4						
PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	-7.03	-4.71	-0.785	4.71	4.65
	2	-7.83	-3.13	-1.57	3.13	5.44
	3	-7.83	-3.92	0	3.92	4.65
	4	-7.03	-3.92	-1.57	3.92	4.65
	5	-7.03	-4.71	-0.785	3.92	5.44
MEAN		-7.35	-4.08	-0.94	3.92	4.97
SDEV		0.39	0.59	0.59	0.50	0.39
SUBJECT: LS5						
PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	-9.44	-7.89	-4.7	2.35	3.86
	2	-8.64	-9.46	-7.03	3.92	5.44
	3	-11.06	-9.46	-6.25	3.92	0
	4	-12.69	-9.46	-5.48	3.92	-1.53
	5	-12.69	-10.25	-6.25	5.5	-1.53
MEAN		-10.90	-9.30	-5.94	3.92	1.25
SDEV		1.65	0.77	0.79	1.00	2.88
SUBJECT: LS6						
PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	-11.06	-7.89	0.785	3.13	6.24
	2	-9.44	-6.29	-0.785	3.13	3.08
	3	-9.44	-6.29	1.57	3.92	1.53
	4	-10.25	-5.5	0.785	3.92	4.65
	5	-7.03	-4.71	0.785	3.92	3.08
MEAN		-9.44	-6.14	0.63	3.60	3.72
SDEV		1.35	1.05	0.77	0.39	1.60

SUBJECT: LS7						
PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	-7.03	-3.13	0.785	0.78	-1.53
	2	-7.03	-3.92	-0.785	1.56	-0.76
	3	-7.83	-3.92	0	1.56	-1.53
	4	-9.44	-4.71	0	0.78	-2.3
	5	-8.64	-3.92	-0.785	0.78	-3.08
MEAN		-7.99	-3.92	-0.16	1.09	-1.84
SDEV		0.94	0.50	0.59	0.38	0.79
SUBJECT: LS8						
PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	-5.44	-0.78	3.92	7.89	6.24
	2	-5.44	0	3.92	7.09	7.83
	3	-5.44	0	4.7	7.89	8.64
	4	-6.24	0	3.92	7.09	8.64
	5	-5.44	0	4.7	6.29	7.83
MEAN		-5.60	-0.16	4.23	7.25	7.84
SDEV		0.32	0.31	0.38	0.60	0.88
SUBJECT: LS9						
PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	-15.94	-8.67	-0.78	6.29	11.06
	2	-15.13	-8.67	-2.35	5.5	11.06
	3	-15.94	-9.46	-2.35	6.29	10.25
	4	-16.76	-10.25	-1.57	5.5	11.06
	5	-16.76	-9.46	-1.57	4.71	11.87
MEAN		-16.11	-9.30	-1.72	5.66	11.06
SDEV		0.61	0.59	0.59	0.59	0.51
SUBJECT: LS10						
PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	-0.76	3.13	4.7	7.89	12.69
	2	0.76	2.35	4.7	5.5	11.87
	3	2.3	2.35	4.7	7.09	11.87
	4	0.76	3.13	3.92	7.09	11.06
	5	0.76	2.35	3.92	6.29	11.06
MEAN		0.76	2.66	4.39	6.77	11.71
SDEV		0.97	0.38	0.38	0.81	0.61

TABLE 7 INDIVIDUAL POINTING RESPONSES - RAW DATA IN INCHES
[DEVIATION FROM TRUE EYE LEVEL - MINUS IS BELOW, PLUS IS ABO
BOX TILT ANGLE DEGREES - PITCH UP (BOTTOM RISES AT BACK) 15

SUBJECT: LS1						
PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	1.30	-0.37	0.05	-0.92	-4.40
	2	0.75	-0.15	-1.75	-0.67	-1.60
	3	-0.75	0.10	-1.60	-0.82	-1.63
	4	0.25	1.80	-0.15	-0.55	-2.10
	5	0.18	0.60	-1.60	-0.70	-2.37
MEAN		0.35	0.40	-1.01	-0.73	-2.42
SDEV		0.68	0.77	0.79	0.13	1.03
SUBJECT: LS2						
PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	-0.25	-0.50	-2.40	-3.15	-3.30
	2	-1.80	-1.20	-2.80	-3.25	-4.00
	3	-1.60	-1.70	-1.80	-2.45	-4.10
	4	-2.60	-2.60	-1.10	-3.00	-3.20
	5	-3.50	-2.15	-1.80	-1.85	-3.40
MEAN		-1.95	-1.63	-1.98	-2.74	-3.60
SDEV		1.08	0.73	0.58	0.52	0.37
SUBJECT: LS3						
PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	0.55	0.45	-0.25	-2.85	-3.18
	2	0.45	0.80	-2.05	-2.80	-3.70
	3	-0.63	-1.45	-1.40	-1.45	-2.20
	4	-0.95	0.23	-1.05	-1.78	-3.05
	5	-0.85	-1.18	-1.65	-2.00	-2.38
MEAN		-0.29	-0.23	-1.28	-2.18	-2.90
SDEV		0.65	0.91	0.61	0.56	0.55
SUBJECT: LS4						
PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	-0.70	-2.75	-2.10	-2.00	-2.35
	2	-1.40	-1.90	-1.30	-2.25	-1.77
	3	-1.40	-1.85	-1.40	-1.63	-2.45
	4	-1.67	-1.35	-2.40	-2.20	-1.90
	5	-1.90	-2.95	-2.83	-1.63	-3.20
MEAN		-1.41	-2.16	-2.01	-1.94	-2.33
SDEV		0.40	0.60	0.58	0.27	0.50

SUBJECT: LS5						
PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	-0.10	0.33	0.10	-0.25	-2.87
	2	1.55	0.63	0.75	-0.85	-2.95
	3	-0.50	0.87	1.23	-0.83	-0.40
	4	0.50	1.57	0.27	-0.80	-1.77
	5	0.30	2.90	-0.55	-0.95	-1.63
MEAN		0.35	1.26	0.36	-0.74	-1.92
SDEV		0.69	0.92	0.60	0.25	0.94

SUBJECT: LS6						
PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	-1.97	-2.55	-2.70	-3.27	-5.25
	2	-2.05	-3.03	-2.37	-3.93	-4.57
	3	-2.83	-2.45	-2.55	-3.40	-4.05
	4	-2.78	-3.10	-2.78	-2.97	-3.85
	5	-2.20	-3.70	-4.27	-4.23	-3.55
MEAN		-2.37	-2.97	-2.93	-3.56	-4.25
SDEV		0.37	0.45	0.68	0.46	0.60

SUBJECT: LS7						
PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	-1.40	-0.62	-1.35	-1.53	-3.23
	2	-1.50	-1.22	-1.00	-1.67	-3.02
	3	-1.23	-2.23	-2.05	-1.58	-4.25
	4	-1.90	-1.25	-1.62	-1.70	-3.63
	5	-2.40	-1.70	-1.35	-2.55	-2.02
MEAN		-1.69	-1.40	-1.47	-1.81	-3.23
SDEV		0.42	0.54	0.35	0.38	0.74

SUBJECT: LS8						
PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	0.00	-0.55	-2.00	-2.60	0.37
	2	0.37	-1.25	-1.85	-2.47	-1.23
	3	0.95	-1.47	-2.25	-2.47	-2.45
	4	0.90	-1.75	-1.70	-2.80	-0.83
	5	1.40	-0.17	-1.27	-2.70	-4.30
MEAN		0.72	-1.04	-1.81	-2.61	-1.69
SDEV		0.49	0.59	0.33	0.13	1.59

SUBJECT: LS9

PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	1.95	-0.15	-1.00	-2.83	-1.40
	2	0.20	0.00	-1.22	-2.15	-2.45
	3	1.57	-0.50	-1.25	-2.10	-2.18
	4	0.85	-0.45	-1.00	-2.47	-2.95
	5	0.20	-0.25	-1.10	-3.22	-2.83
MEAN		0.95	-0.27	-1.11	-2.55	-2.36
SDEV		0.71	0.19	0.11	0.42	0.55

SUBJECT: LS10

PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	-4.40	-5.60	-5.25	-5.70	-6.80
	2	-3.98	-6.18	-5.25	-6.07	-6.60
	3	-4.10	-5.82	-5.15	-5.57	-6.80
	4	-3.62	-5.62	-5.15	-6.37	-6.95
	5	-4.78	-5.23	-4.82	-6.73	-6.30
MEAN		-4.18	-5.69	-5.12	-6.09	-6.69
SDEV		0.39	0.31	0.16	0.43	0.22

TABLE 8 INDIVIDUAL POINTING RESPONSES - CORRECTED DATA IN IN
[DEVIATION FROM TRUE EYE LEVEL - MINUS IS BELOW, PLUS IS ABO
BOX TILT ANGLE DEGREES - PITCH UP (BOTTOM RISES AT BACK) IS

SUBJECT: LS1

PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	3.06	-0.80	0.15	-2.43	-11.60
	2	1.52	-0.15	-5.26	-1.69	-3.90
	3	-1.52	0.00	-4.81	-2.13	-3.98
	4	0.12	5.03	-0.45	-1.34	-5.29
	5	-0.08	1.48	-4.81	-1.78	-6.04
MEAN		0.62	1.11	-3.04	-1.87	-6.16
SDEV		1.55	2.10	2.37	0.37	2.84

SUBJECT: LS2

PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	-0.12	-1.19	-7.20	-8.97	-8.61
	2	-4.46	-3.26	-8.38	-9.26	-10.52
	3	-3.90	-4.73	-5.41	-6.93	-10.79
	4	-6.68	-7.37	-3.31	-8.53	-8.34
	5	-9.16	-6.05	-5.41	-5.17	-8.89
MEAN		-4.86	-4.52	-5.94	-7.77	-9.43
SDEV		3.01	2.15	1.73	1.53	1.02

SUBJECT: LS3						
PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	0.96	1.04	-0.75	-8.10	-8.28
	2	0.68	2.08	-6.16	-7.95	-9.71
	3	-1.18	-3.48	-4.21	-4.00	-5.57
	4	-2.08	0.39	-3.16	-4.97	-7.92
	5	-1.80	-3.20	-4.96	-5.60	-6.07
MEAN		-0.68	-0.63	-3.85	-6.12	-7.51
SDEV		1.27	2.28	1.83	1.63	1.51
SUBJECT: LS4						
PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	-1.40	-7.81	-6.31	-5.61	-5.99
	2	-3.34	-5.32	-3.91	-6.35	-4.37
	3	-3.34	-5.17	-4.21	-4.53	-6.27
	4	-4.09	-3.70	-7.20	-6.20	-4.74
	5	-4.74	-8.39	-8.47	-4.53	-8.34
MEAN		-3.38	-6.08	-6.02	-5.44	-5.94
SDEV		1.12	1.75	1.74	0.79	1.40
SUBJECT: LS5						
PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	0.30	0.68	0.30	-0.45	-7.43
	2	3.76	1.57	2.26	-2.22	-7.65
	3	-0.82	2.28	3.70	-2.16	-0.54
	4	0.82	4.35	0.81	-2.08	-4.37
	5	0.26	8.24	-1.66	-2.52	-3.98
MEAN		0.86	3.42	1.08	-1.89	-4.79
SDEV		1.54	2.70	1.81	0.73	2.61
SUBJECT: LS6						
PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	-4.93	-7.22	-8.09	-9.31	-13.87
	2	-5.15	-8.62	-7.11	-10.33	-12.06
	3	-7.32	-6.93	-7.64	-9.69	-10.66
	4	-7.18	-8.82	-8.32	-8.45	-10.11
	5	-5.57	-10.55	-12.67	-12.06	-9.30
MEAN		-6.03	-8.43	-8.77	-9.97	-11.20
SDEV		1.02	1.30	2.00	1.21	1.61

SUBJECT: LS7						
PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	-3.34	-1.54	-4.06	-4.23	-8.42
	2	-3.62	-3.32	-3.01	-4.64	-7.84
	3	-2.86	-6.29	-6.16	-4.38	-11.20
	4	-4.74	-3.41	-4.87	-4.73	-9.51
	5	-6.13	-4.73	-4.06	-7.22	-5.07
MEAN		-4.14	-3.86	-4.43	-5.04	-8.41
SDEV		1.17	1.58	1.05	1.10	2.02
SUBJECT: LS8						
PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	-0.59	-1.33	-6.01	-7.37	0.45
	2	0.45	-3.41	-5.56	-6.99	-2.86
	3	2.08	-4.06	-6.75	-6.99	-6.27
	4	1.94	-4.88	-5.11	-7.45	-1.74
	5	3.34	-0.21	-3.82	-7.66	-11.33
MEAN		1.44	-2.78	-5.45	-7.29	-4.35
SDEV		1.37	1.74	0.98	0.26	4.11
SUBJECT: LS9						
PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	4.88	-0.15	-3.01	-8.04	-3.34
	2	-0.02	-0.30	-3.67	-6.05	-6.27
	3	3.82	-1.19	-3.76	-5.91	-5.52
	4	1.80	-1.04	-3.01	-6.99	-7.65
	5	-0.02	-0.45	-3.31	-9.17	-7.32
MEAN		2.09	-0.63	-3.35	-7.23	-6.02
SDEV		1.99	0.41	0.32	1.23	1.54
SUBJECT: LS10						
PITCH ANGLE		-15	-7.5	0	7.5	15
TRIAL						
	1	-11.60	-15.88	-15.45	-16.16	-17.89
	2	-10.47	-17.46	-15.45	-17.16	-17.38
	3	-10.79	-16.48	-15.17	-15.80	-17.89
	4	-9.49	-15.94	-15.17	-17.97	-18.27
	5	-12.62	-14.86	-14.24	-18.93	-16.61
MEAN		-10.99	-16.12	-15.10	-17.20	-17.61
SDEV		1.06	0.85	0.45	1.15	0.57

APPENDIX D. GRAPHS OF INDIVIDUAL DATA

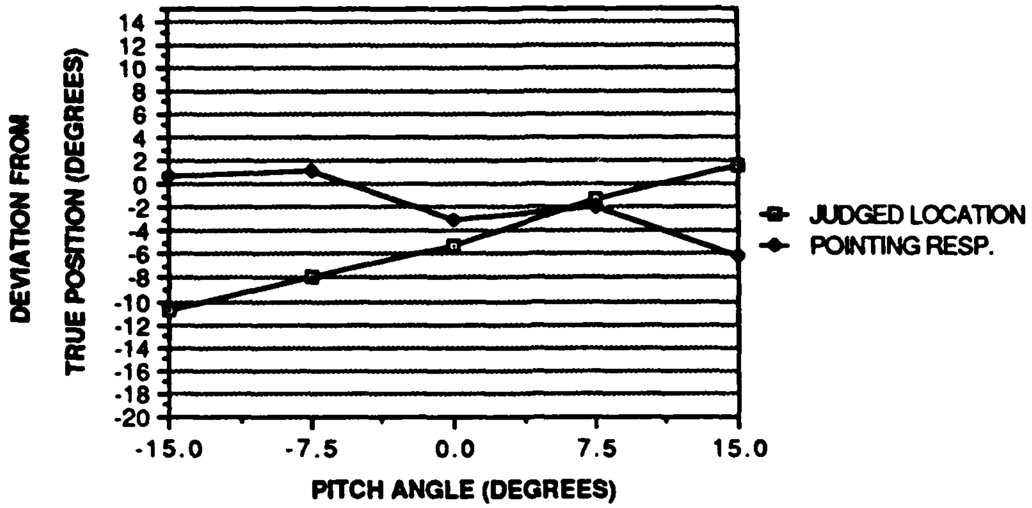

Figure 8. Mean Apparent Eye Level (LS1) as a Function of Pitch Angle

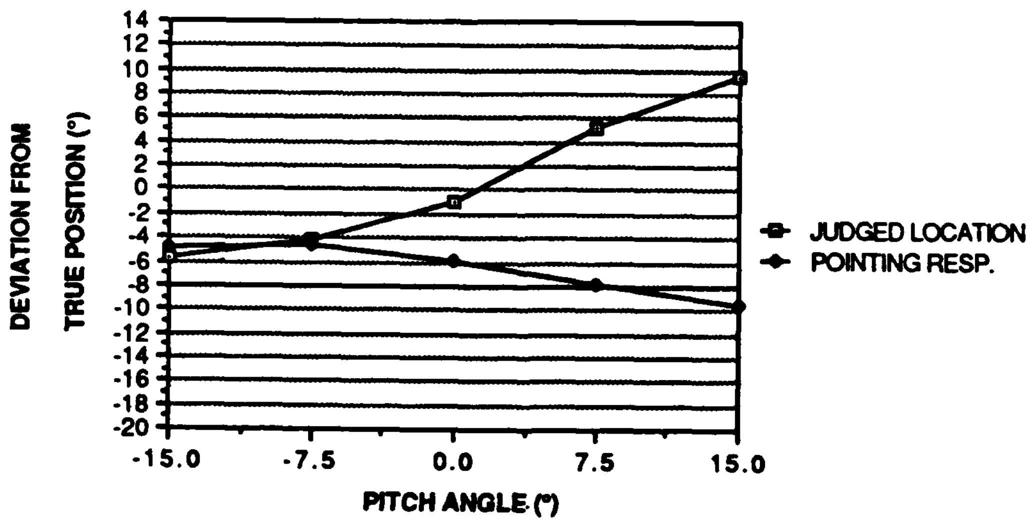

Figure 9. Mean Apparent Eye Level (LS2) as a Function of Pitch Angle

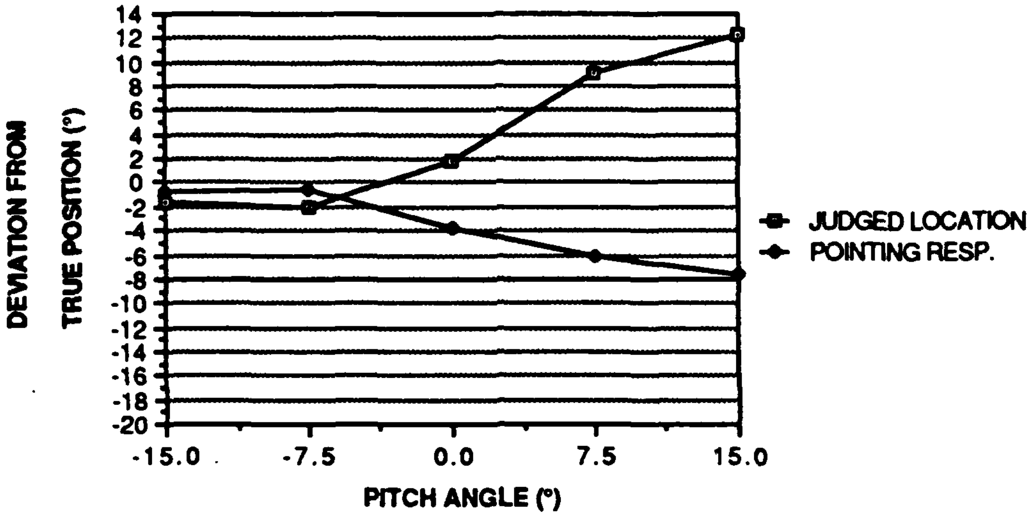

Figure 10. Mean Apparent Eye Level (LS3) as a Function of Pitch Angle

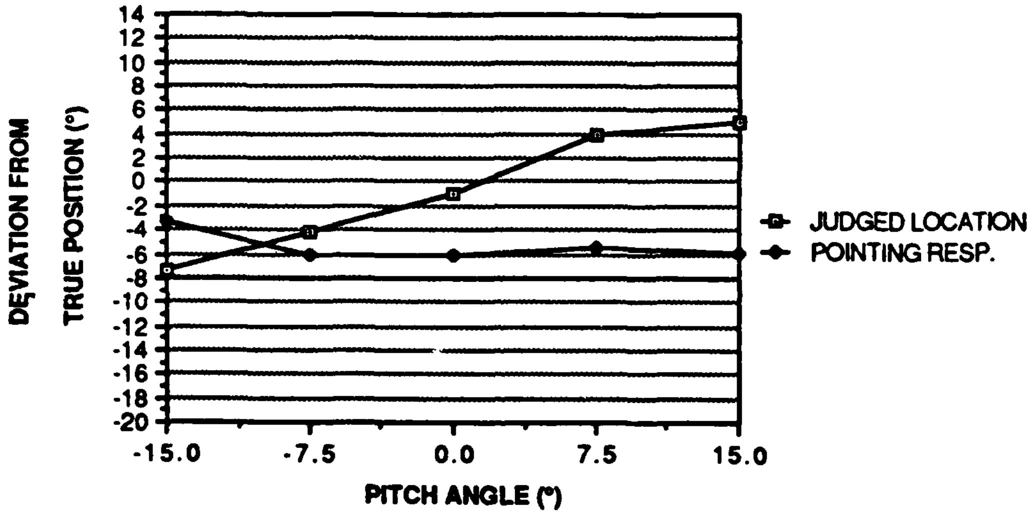

Figure 11. Mean Apparent Eye Level (LS4) as a Function of Pitch Angle

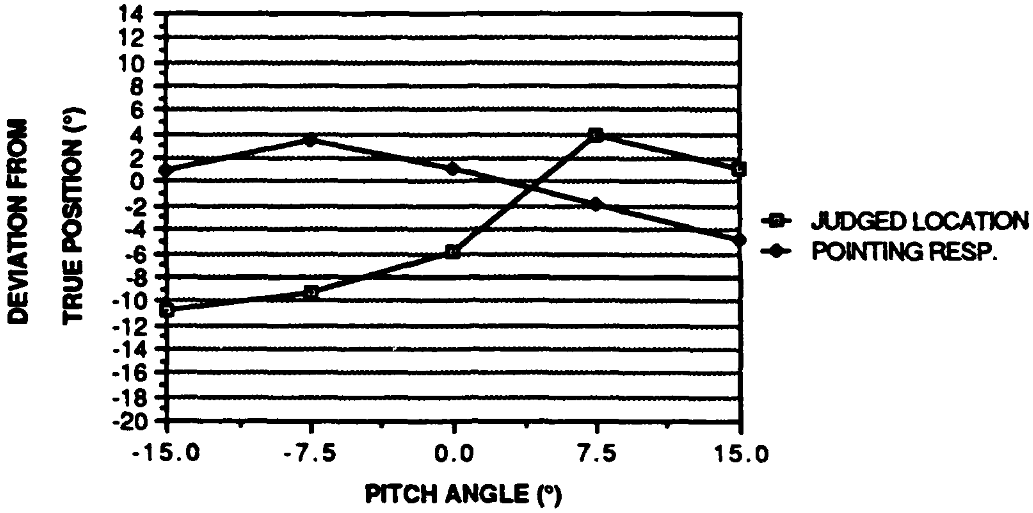

Figure 12. Mean Apparent Eye Level (LS6) as a Function of Pitch Angle

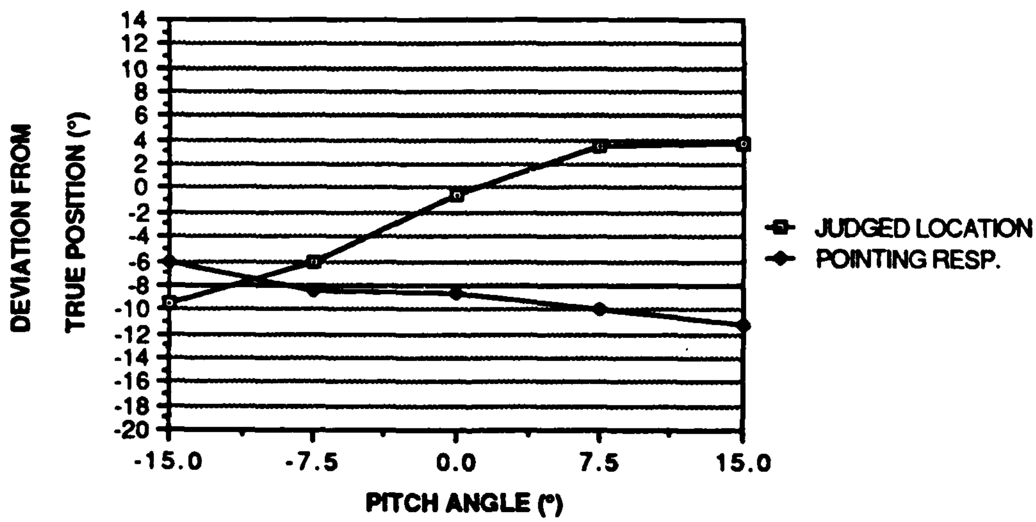

Figure 13. Mean Apparent Eye Level (LS6) as a Function of Pitch Angle

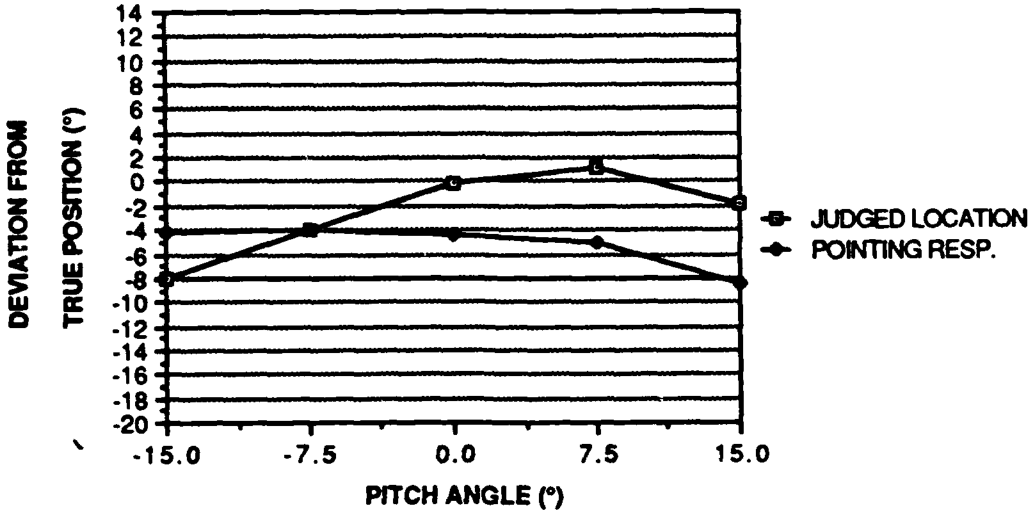

Figure 14. Mean Apparent Eye Level (LS7) as a Function of Pitch Angle

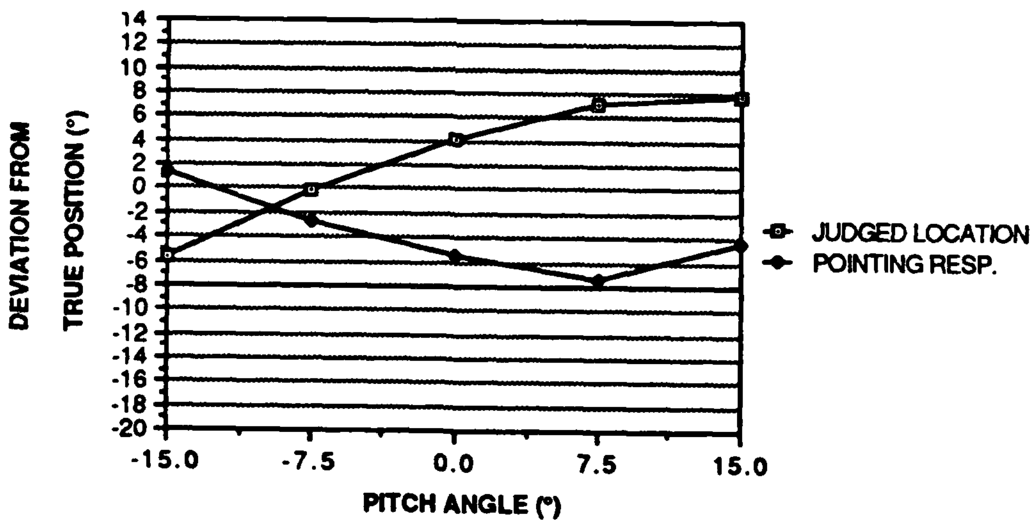

Figure 15. Mean Apparent Eye Level (LS8) as a Function of Pitch Angle

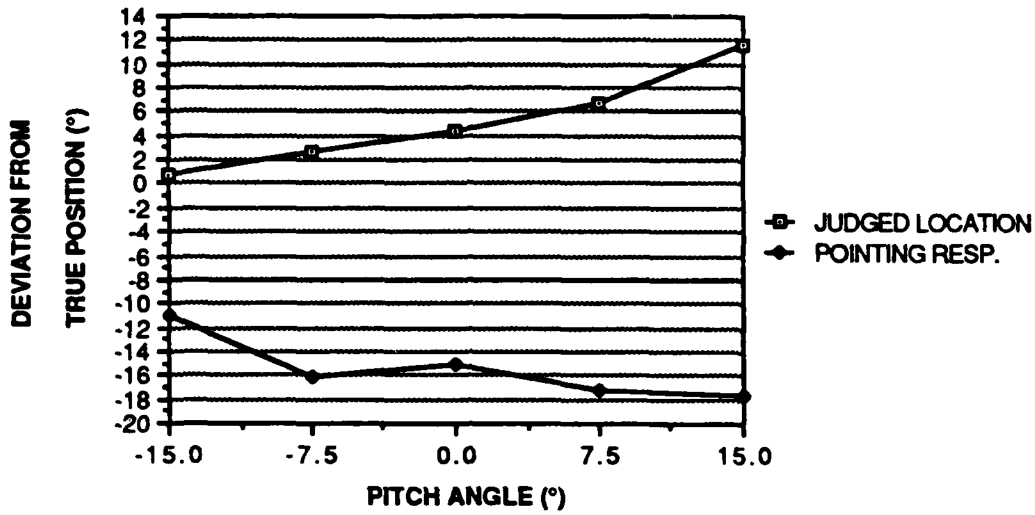

Figure 16. Mean Apparent Eye Level (LS9) as a Function of Pitch Angle

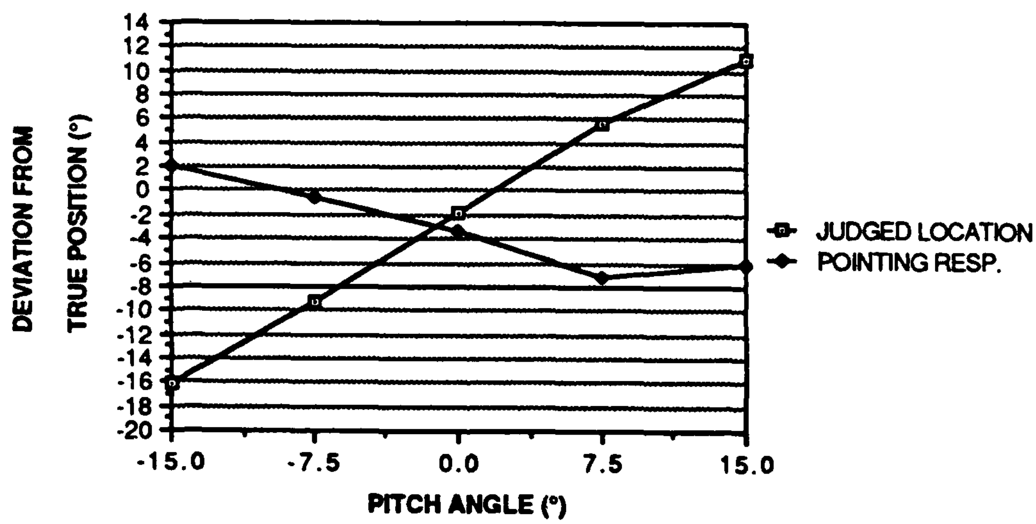

Figure 17. Mean Apparent Eye Level (LS10) as a Function of Pitch Angle

REFERENCES

1. Cohen, M. M.: "Visual-Proprioceptive Interactions." In Richard D. Walk and Herbert L. Pick (Eds), *Intersensory Perception And Sensory Interaction*, pp. 175-214, Plenum Publishing Corporation, 1981.

2. Welch, R. B., *Perceptual Modification Adapting To Altered Sensory Environments*, Academic Press, 1978.

3. Harris, C. S., "Perceptual Adaptation To Inverted, Reversed, And Displaced Vision," *Psychology Review*, v. 72, no.6, pp. 419-444, 1963.

4. Harris, C. S., "Adaptation To Displaced Vision: Visual, Motor, Or Proprioceptive Change?," *Science*, v.140, pp. 812-813, 1963.

5. Efstathiou, A., Bauer, J., Greene, M., and Held, R., "Altered Reaching Following Adaptation To Optical Displacement Of The Hand," *J. of Exp. Psychol.*, v. 73(1), pp. 113-120,1967.

6. Howard, I. P. and Templeton, W. B., *Human Spatial Orientation*, John Wiley and Sons, 1966.

7. Ebenholtz, Sheldon M., "Perception Of The Vertical With Body Tilt In The Median Plane," *J. of Exp. Psychol.*, v. 83(1), pp. 1-6,1970.

8. Asch, S. E., and Witkin, H. A., "Studies in Space Orientation. I. Perception of the Upright With Displaced Visual Fields," *J. of Exp. Psychol.*, v. 38, no. 3, pp. 325-337, June 1948.

9. Asch, S. E. and Witkin, H. A., "Studies in Space Orientation. II. Perception of the Upright With Displaced Visual Fields and With Body Tilt," *J. of Exp. Psychol.*, v. 38, no.4, pp. 455-477, Aug. 1948.

10. Witkin, H. A., and Asch, S.E., "Studies in Space Orientation. III. Perception of the Upright in the Absence of a Visual Field,"*J. of Exp. Psychol.*, v. 38, no. 5, pp. 603-614, Oct. 1948.

11. Bauermeister, M. "Effect Of Body Tilt On Apparent Verticality, Apparent Body Position, And Their Relation,"*J. of Exp. Psychol.*,v. 67, pp. 142-147,1964.

12. Bauermeister, M. W. H., & Wapner, S. "The Effect Of Body Tilt On Tactile-Kinesthetic Perception Of Verticality," *American Journal of Psychology*, v. 77, pp. 451-456,1964.

13. Naval Air Development Center Report 75187-40, *Human Spatial Orientation In The Pitch Dimension*, M. M. Cohen, pp. 508-512, 6 June 1975.

14. Stoper, A.d E., and Cohen, M. M., "Optical, Gravitational, and Kinesthetic Determinants Of Judged Eye Level," pp. 1-17.

15. Halliday, D. and Resnick, R., *Fundamentals of Physics*, 2d ed., John Wiley and Sons,1970.

16. Cohen, M. M., "Sensory-motor Adaptation and After-effects of Exposure to Increased Gravitational Forces," *Aerospace Medicine*, v. 41(3), pp. 318-322, 1970.

17. Cohen, M. M., "Hand-Eye Coordination in Altered Gravitational Fields," *Aerospace Medicine*, v. 41(6), pp. 647-649, 1970.

18. Stoper, A. E. and Cohen, M. M., "Judgements of eye level in light and darkness," *Perception & Pshychophysics*, v. 40(5), pp. 311-316, 1986.

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center..2
   Cameron Station
   Alexandria, VA 22304-6145

2. Library, Code 0142..2
   Naval Postgraduate School
   Monterey, CA 93943-5002

3. Commander..1
   Naval Space Command
   Attn: Code N3
   Dahlgren, VA 22448

4. Commander..1
   United States Space Command
   Attn: Technical Library
   Peterson AFB, CO 80914

5. Navy Space System Division...1
   Chief of Naval Operations (OP-943)
   Washington, DC 20305-2000

6. Space Systems Academic Group..1
   Attn: Prof. Panholzer (Code 72)
   Naval Postgraduate School
   Monterey, CA 93943-5000

7. Commander..1
   Naval Air Development Center
   Attn: Technical Library
   Worminster, PA 18974-5000

8. NASA-AMES Research Center...1
   Attn: Dr. M. M. Cohen
   Moffett Field, CA 94035

9. Commander..2
   United States Space Command
   Attn: LT Ballinger
   Peterson AFB, CO 80914